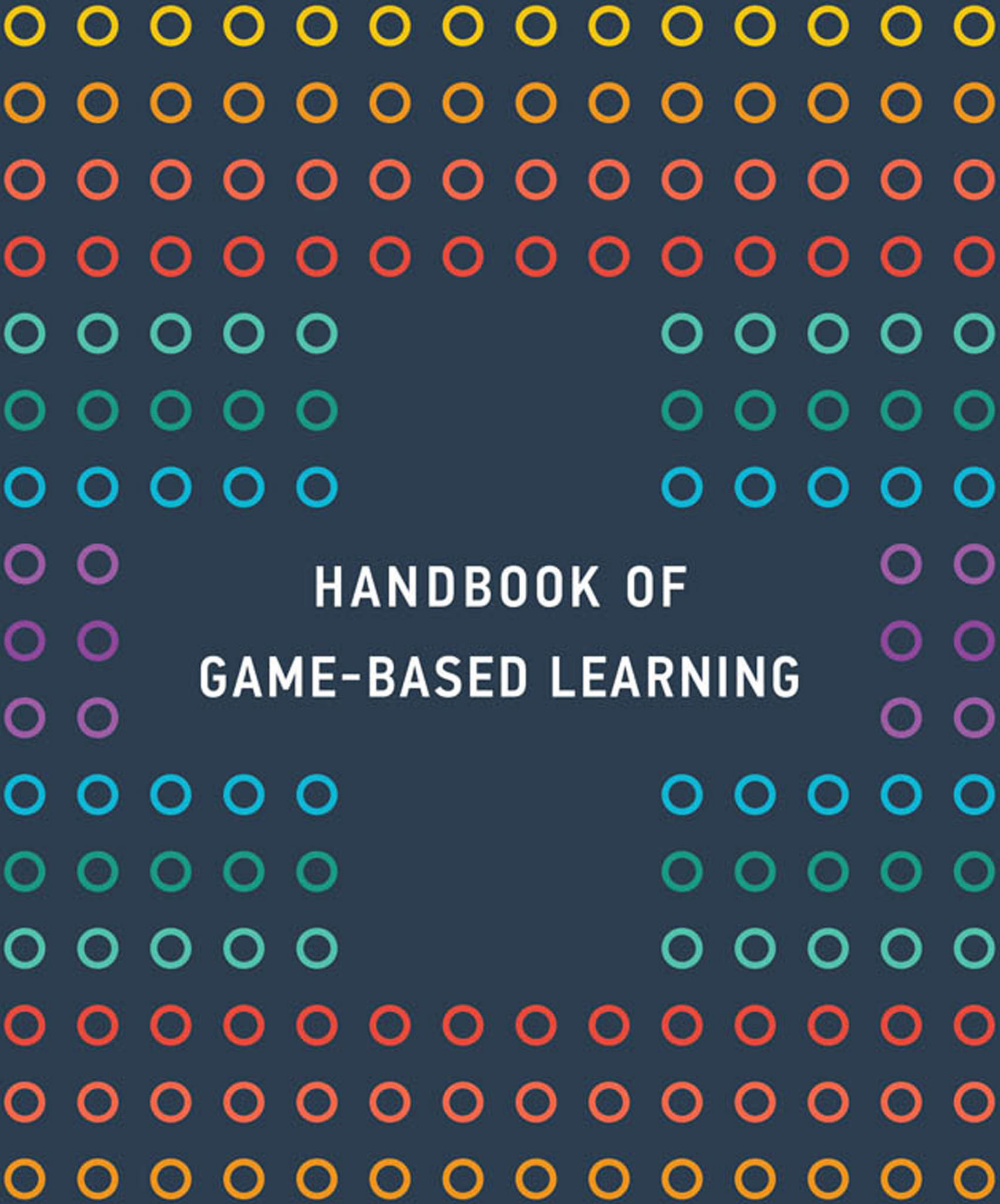

HANDBOOK OF GAME-BASED LEARNING

EDITED BY JAN L. PLASS, RICHARD E. MAYER, AND BRUCE D. HOMER

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Preface

Objective

Can you learn academic content or skills by playing computer games? If so, what is the best way to design computer games so they maximize your learning? How does game-based learning work? These are the kinds of questions addressed in *Handbook of Game-Based Learning*. For the purposes of this handbook, game-based learning refers to academic learning from playing computer games (also called video games or digital games). If you are interested in what research has to say about game-based learning, then this handbook is for you.

The goal of this handbook is to give you a comprehensive introduction to research on learning and instruction with computer games. Concerning learning, it explores research on whether and how computer games can help students learn academic content (such as in science, mathematics, or history) and academic skills (such as how to keep your attention focused on the key material). Concerning instruction, it explores research on which game features (such as feedback, coaching, or adaptivity) can improve the instructional effectiveness of computer games. In short, the goal of the handbook is to help establish a solid empirical and theoretical foundation for the discipline of game-based learning that synthesizes and organizes existing research and sets a research agenda for years to come.

Description

Handbook of Game-Based Learning is a comprehensive volume summarizing research and theory in the field of game-based learning. Our approach to understanding the empirical and theoretical foundations of game-based learning is that no single perspective alone can suffice. Instead, the volume includes cognitive, motivational, affective, and sociocultural perspectives. In doing so, it is the first comprehensive volume describing how people learn from digital game-based environments. The chapters are based on empirical research and grounded in psychological theory rather than being descriptions of development efforts or best practices. The chapter authors are research leaders from around the world, each having a record of research publications in game-based learning.

As editors, we recruited the world's leading game-based learning researchers to write chapters in areas in which they have contributed to the empirical research base. We gave each chapter author a specific charge, based on clear directions to review empirical research on a well-defined topic. To maintain consistency for the reader, we asked authors to follow the same general structure: summarize the main theme, describe the major research issue or question, provide examples of the research issue or question, summarize research in which broadly defined measures of learning outcome are the central focus, critique the research, and discuss implications for theory and practice.

There are many books providing advice on how to design game-based learning environments, but these books are largely based on the practical experience and wisdom of the authors. Similarly, there are many advocacy books that make strong claims about revolutionizing education based on games but lack adequate empirical evidence. Finally, there are books describing the development of computer games for learning, but these books can lack supporting research evidence for the effectiveness of the games. Until recently, the lack of scientific research evidence in many game-based learning books could be justified on the grounds that a solid research base did not exist. However, the quantity and quality of scientifically sound research—conducted by researchers around the world—has reached a level warranting the compilation of the field's most comprehensive research-based handbook of game-based learning.

Organization

The book is organized into four sections: Introduction, Psychological Foundations, Design Foundations, and Applications. Part I, Introduction to Game-Based Learning, includes chapters on the theoretical foundations of game-based learning (chapter 1), play and cognitive development (chapter 2), and engagement with games (chapter 3). Part II, Theoretical Foundations of Game-Based Learning, documents four complementary theoretical approaches to game-based learning: cognitive foundations (chapter 4), emotional foundations (chapter 5), motivational foundations (chapter 6), and sociocultural foundations (chapter 7). Part III, Design Foundations of Game-Based Learning, explores the research evidence concerning features that are intended to increase the educational effectiveness of games: instructional support, feedback, and coaching (chapter 8), self-regulation and reflection (chapter 9), adaptivity (chapter 10), narrative theme (chapter 11), multimedia design (chapter 12), collaboration and cooperation (chapter 13), emotional design, musical score, and game mechanics design (chapter 14), and incentives, social presence, and identity design (chapter 15). Part IV, Applications of Game-Based Learning, explores venues for game-based learning: games for learning in STEM disciplines (chapter 16), games for learning second languages (chapter 17), games for training cognitive skills (chapter 18), games for workforce learning (chapter 19), games for assessment (chapter 20), and learning analytics in games (chapter 21). These four sections contain chapters that cover the current state of the field and for which a sufficient research base exists.

Audience

The intended audience for this handbook includes anyone interested in taking an evidence-based approach to how people learn from digital games. Although the handbook summarizes the research base for game-based learning, it is intended to be accessible to a general audience. On the one hand, it is designed to support readers with practical interests in how to design or select game-based learning environments that promote learning. On the other hand, it is designed to support readers who have academic interests in conducting or evaluating research in game-based learning.

This handbook is appropriate for a wide variety of courses related to cognition, motivation, affect, instruction, and technology. It would also be useful for instructors interested in designing or improving game-based learning modules in school settings, job training, and informal environments. In short, it belongs on the bookshelf of anyone who is interested in an evidence-based approach to learning and instruction with digital games, instructional technology, human-computer interaction, educational psychology, applied cognitive psychology, applied social psychology, or applied motivational science.

Rationale

Game-based learning is a dynamic field that has garnered much interest from a broad range of stakeholders, yet no comprehensive research-based handbook exists. This handbook is the first such volume to take into account the various perspectives of this emerging field and focus on research evidence. It is our goal that it will help define and shape this field and will become recognized as its major reference work.

This handbook is based on the premise that computer games have the potential to improve academic learning, but research is needed to determine how best to fulfill this potential. Although game technology is advancing at an impressive pace, the underlying research base on game-based learning is in its initial stages. This handbook is intended to give you a state-of-the-art overview of what research has to say about game-based learning and how to improve it.

Acknowledgments

We gratefully acknowledge the talented group of chapter authors who have worked diligently to systematize and interpret the research base on game-based learning. We also gratefully acknowledge the determined band of researchers who have produced and disseminated high-quality research on game-based learning. We appreciate the staff of MIT Press, who helped bring out this handbook. Finally, we wish to acknowledge the following grants, which have supported our research and the preparation of this book: grant R305A150417 from the Institute of Education Sciences and grant N000141612046 from the Office of Naval Research.

Jan L. Plass
New York, New York

Richard E. Mayer
Santa Barbara, California

Bruce D. Homer
New York, New York

I Introduction to Game-Based Learning

1 Theoretical Foundations of Game-Based and Playful Learning

Jan L. Plass, Bruce D. Homer, Richard E. Mayer, and Charles K. Kinzer

Educators have long been fascinated with the question of how to leverage the appeal of play for the purpose of learning (Gee, 2007). At the time of the printing of this volume, reports show that 95% of teens in the United States are online, and 45% say they are online almost constantly, primarily via smartphones (Smith & Anderson, 2018). Even children eight years and younger spend over two hours a day with screen-based media, and 42% own their own tablet device (Common Sense Media Report, 2017). Although a large amount of this time is spent on social media, we know from previous reports that 99% of boys and 94% of girls play video games (Lenhart et al., 2008). In a study with middle school youths in New York City, we found that boys play over 42 hours and girls play 30 hours of video games per week (Homer et al., 2012). This growing use of digital devices and corresponding digital media has focused researchers' and educators' interest on the use of digital games for learning. Because games are able to engage a broad range of people in a range of individual and social learning activities, advocates argue that games are an ideal medium for learning (Gee, 2007; Prensky, 2003; Squire, 2011), and this quest to enhance learning through playful activities continues in our current digital environment.

What Is Game-Based Learning?

Salen and Zimmerman (2004) define a game as "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (p. 5). To extend the definition, games for learning may be defined as games with specific learning goals. There is no general agreement among theorists on the definition of games, but many agree on the characteristics of games (Mayer, 2014): they are rule based, following clearly defined rules of play; they are responsive, enabling player actions and providing system feedback and responses; they are challenging, often including an element of chance; the progress within a game is usually cumulative, reflecting previous actions; and finally, games are inviting, motivating the player to engage (Mayer, 2014). These characteristics are achieved using the design elements that collectively make a game, namely game mechanics, an incentive structure, visual aesthetics, auditory aesthetics, and a narrative (Plass, Homer, & Kinzer, 2015).

Games for learning are unique in that the goal of facilitating learning creates a tension in the design process that requires careful balancing of the need to cover the subject matter and the desire to promote gameplay (Plass, Perlin, & Nordlinger, 2010). If the focus is too much on achieving the learning objectives, the resulting environment may not actually feel like a game, since important elements of a game, such as playfulness and player choice, may be lost. In contrast, if the focus is too much on gameplay, then features supporting playfulness may get in the way of learning. The design process therefore has to carefully calibrate how much each of these two design objectives—learning outcomes versus playfulness—should influence specific design decisions.

Table 1.1 contrasts game-based learning with two other approaches—gamification and playful learning. *Gamification* involves the addition of specific game features, mainly involving the reward system and narrative structure, to an existing (nongame) learning environment in order to make it more motivating. Gamification involves adding incentives such as stars, points, achievements, or rankings to encourage the learner to expend effort on an otherwise unengaging or tedious task. The learning task itself, however, remains largely unchanged. Airline reward programs, which have existed for several decades, are an early example of gamification. Rather than redesigning the flight experience itself, these programs use points and elite status to gamify flying and attract customers to their airline. In the context of learning, this is usually considered a missed opportunity to rethink and redesign the learning task. In some cases, however, such as Cole's (2006) *5th Dimension* afterschool program, gamification may be successful in facilitating learning (Steinkuehler & Squire, 2014).

In contrast to gamification, *game-based learning* means a learning task is redesigned as to make it more interesting, meaningful, and, ultimately, more effective for learning than either a nongame or gamified task. In other words, we design effective learning

Table 1.1
Game-based learning, gamification, and playful learning

	Learning activity	Game features	Example
Gamification	Largely unchanged	Mostly use of extrinsic rewards	Gamified worksheets
Playful learning	Redesigned to be more relevant, meaningful, and interesting	Mostly use of intrinsic rewards	Simulation with playful feedback
Game-based learning	Redesigned to be more relevant, meaningful, and interesting	Use of full range of game features	Learning game

mechanics, the recurring activities in which learners engage while they play the game (Plass et al., 2012), from the ground up, taking advantage of the unique affordances of games. This redesign is based on insights from education, pedagogy, and the learning sciences, as well as from discipline-specific theory and research (Plass & Homer, 2012; Plass, Homer, et al., 2013). The result encompasses a new pedagogy and a new way of learning that, if successful, would not just be considered a good learning task but also a good game.

Playful learning takes a different approach, as it is based on the idea that a full game is not always needed when a learning task is redesigned to make it more effective in terms of relevance, meaning, and interest. Taking a playful learning approach means that a learning activity may be redesigned, but game features are used only in subtle ways to create a playful experience but not a complete game. For example, only feedback in a game mechanic may become playful, using animations to provide a feeling of responsiveness. To some extent, this approach is the opposite of gamification—rather than adding game features without changing the learning approach, the learning approach is changed to include some game features in the instructional task.

Examples of Game-Based Learning

It is difficult to select a single example of game-based learning because games for learning is a genre of learning environment that spans a broad range of fields (e.g., humanities, sciences, engineering, second-language learning, science, history) as well as genres of games (e.g., casual, first-person shooter, massively multiplayer online, role-playing).

We therefore take a different approach and provide examples of games based on their function, or overall goal, related to learning. We distinguish four functions, preparing for future learning, acquiring new knowledge and skills, practicing existing knowledge or skills, and developing learning and innovation skills, sometimes referred to as twenty-first-century skills (Pellegrino & Hilton, 2012; Plass et al., 2015).

Preparing for Future Learning

Games aimed at preparation for future learning do not necessarily have their own domain-specific learning outcomes. Instead, they are intended to provide students with shared experiences that can be used for later learning activities, such as class discussions or problem-solving activities outside the game. For example, the game *Impulse* (TERC Edge, 2016) uses a mechanic in which players can direct green balls into blue goals using impulses, as shown in figure 1.1. The game itself does not directly teach about impulse, momentum, or related concepts, but having played the game, students can engage in a discourse about these topics in Newtonian mechanics based on the gameplay each of them experienced (Rowe et al., 2017).

Figure 1.1
Screenshot of game *Impulse* (TERC Edge, 2016).

Learning New Knowledge and Skills

This type of game introduces new knowledge and skills for the learner to acquire as part of the gameplay. Games that teach new academic knowledge are less common, as playfulness is often impacted when doing so, but an example of this type of game is *Immune Attack* (FAS, 2008). In this game, players learn about the cells and environment of the human body and how the immune system defends against viral and bacterial infections. They learn by remotely controlling a nanobot that can teach cells how to fight infections, as shown in figure 1.2. The game teaches players about the human immune system by giving hints and asking learners to gather information in the environment and then train specialized immune cells to defend against increasingly sophisticated bacteria and viruses (Stegman, 2014).

Practicing and Reinforcing Existing Knowledge and Skills

This type of game assumes that the basic knowledge or skill already exists, and provides opportunity either to deepen this knowledge by applying it to problems in different contexts and with different features, or to automate skills by repeatedly applying them. As shown in figure 1.3, an example of this type of game is *Gwakkamole* (CREATE, 2017), a game designed to train the executive function skill of *inhibition*. In this game,

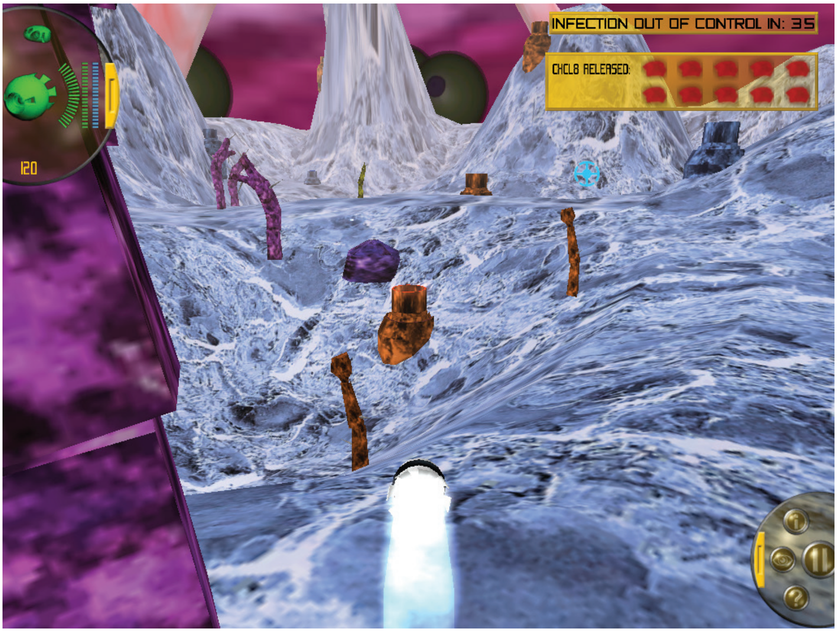

Figure 1.2
Screenshot of *Immune Attack* (Kelly et al., 2007).

different avocados pop up from the ground, and the rules of play specify which ones the player should smash and which they shouldn't. This need to inhibit the initial response to smash all avocados is designed to train this cognitive skill (Homer et al., 2019).

Developing Learning and Innovation Skills

This type of game provides opportunities to develop socioemotional skills of greater complexity related to teamwork, collaboration, problem solving, creativity, communication, and the like. Typical games for this kind of learning are massively multiplayer online (MMO) or other open-ended games allowing online collaboration. For example, the game *World of Warcraft* has been shown to involve a series of activities that can help players develop these skills (Steinkuehler, 2008).

What Do We Know about Game-Based Learning?

Drawing general conclusions about games as learning environments is difficult because of the large range of areas for which they are used, topics they cover, genres they represent, and age ranges they target. For example, games may have health-related goals,

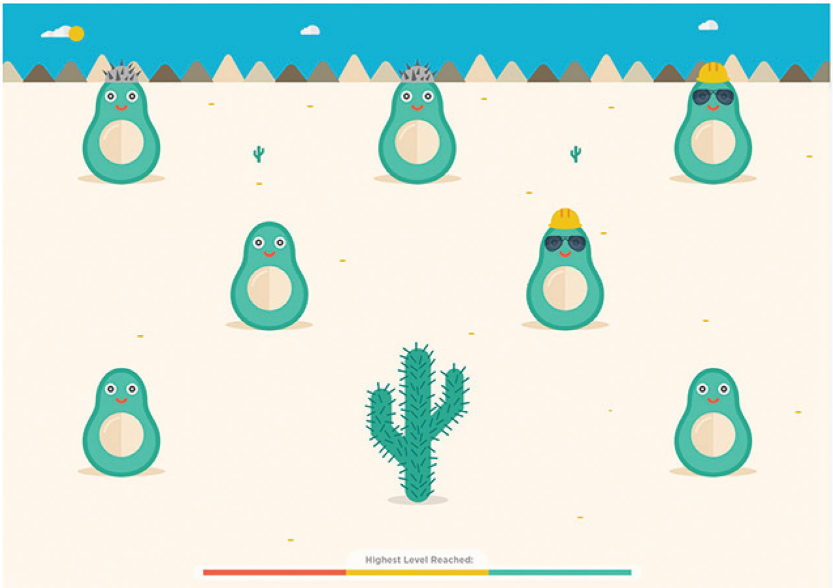

Figure 1.3
Screenshot of *Gwakkamole* (CREATE, 2017).

such as supporting smoking secession or increasing exercise levels; aim to educate individuals about significant news, such as humanitarian disasters; promote peace; support scientific exploration; or increase knowledge about city planning or emergency management. This broad range of uses and genres makes it difficult to make general statements about the effectiveness of games for learning. However, what has become clear is that we need to take an evidence-based approach to the study of games for learning.

Recognition of the need for an evidence-based approach to game-based learning dates back to the early days of video games, as reflected in the musings of Loftus and Loftus (1983) in their classic book *Mind at Play: The Psychology of Video Games*: "It would be comforting to know that the seemingly endless hours young people spend playing Defender and Pac-Man were really teaching them something useful" (p. 121).

Today, almost 40 years later, a growing body of research allows us to take an evidence-based approach to game-based learning (e.g., Blumberg, 2014; Honey & Hilton, 2011; Mayer, 2014; O'Neil & Perez, 2008; Tobias & Fletcher, 2011; Wouters & van Oostendorp, 2017). But what do we know about game-based learning? Mayer (2014, 2019) has organized the research literature on the instructional effectiveness of computer games into three genres: value-added research, cognitive consequences research, and media comparison research.

Value-added research seeks to identify game features that promote learning of academic content. It involves comparing the learning outcomes of students who learn from a base version of a game versus learning from the same game with one feature added. In a search for features that produce a median effect size greater than $d = 0.4$ on learning outcome posttests based on at least five experimental comparisons, Mayer (2014, 2019) identified five promising features of computer games in education:

- *modality*—using spoken text rather than printed text produced a median effect size of $d = 1.4$ across nine experiments.
- *personalization*—using conversational language rather than formal language produced a median effect size of $d = 1.5$ across eight experiments.
- *pretraining*—adding pregame information or experiences caused a learning improvement equivalent to a median effect size of $d = 0.8$ across seven experiments.
- *coaching*—adding in-game advice and feedback caused a learning improvement equivalent to a median effect size of $d = 0.7$ based on 15 experiments.
- *self-explanation*—adding prompts for players to explain or reflect during the game caused a learning improvement equivalent to a median effect size of $d = 0.5$ based on 16 experiments.

Research is ongoing to test the instructional effectiveness of other features, such as competition (e.g., by showing the player's score in relation to other players), segmenting (breaking a complicated screen into parts), image (including an agent's image on the screen), narrative theme (adding an engaging story line), choice (allowing the player to choose the game format, avatar appearance, etc.), and learner control (allowing the player to control the order of game levels, level of difficulty, etc.). Overall, the value-added approach offers general principles for game design. The value-added approach to game research is well represented in this handbook and offers a powerful methodology for answering questions about what works in game design.

Cognitive consequences research seeks to determine whether playing an off-the-shelf game causes improvements in the player's educationally relevant cognitive skills. This research involves comparing the pretest-to-posttest gains of students playing a game for a period of time versus those who play a control game for the same period (i.e., active control) or no game at all (i.e., inactive control). For example, Mayer (2014, 2019) identified two promising cognitive consequences of playing video games:

- *Action video games* (first-person shooter games), such as *Unreal Tournament* or *Medal of Honor*, cause improvements in perceptual attention skills, yielding a median effect size of $d = 1.2$ based on 18 experiments. In a more focused meta-analysis, Bediou et al. (2018) also found that playing action video games for an extended time resulted in greater improvements in related cognitive skills, such as perceptual attention, compared to a control group.

- *Spatial puzzle games* such as *Tetris* cause improvements in two-dimensional mental rotation skill but not in other spatial skills, yielding a median effect size of $d=0.8$ based on six experiments.

Interestingly, brain-training games—which contain gamified versions of cognitive skill tasks—generally have not been effective in promoting cognitive skills outside the game context. For example, Bainbridge and Mayer (2018) found that playing the brain-training game *Lumosity* for up to 80 sessions did not result in broad improvements in cognitive skills as compared to a control group. In contrast, Parong et al. (2017) found that a focused computer game, designed to train a specific cognitive skill based on cognitive theories of skill learning, was effective. This suggests that game design for cognitive skill training should encourage players to engage in repeated practice on the target skill in varied contexts at increasing levels of challenge with feedback (Mayer, Parong, & Bainbridge, 2019). The cognitive consequences approach is also well represented in this handbook and addresses the issue raised by Loftus and Loftus (1983) about whether players learn anything useful from playing computer games. For games with learning goals that go beyond cognitive outcomes, similar types of research can also be conducted for affective, motivational, or sociocultural consequences.

Media comparison research investigates whether students learn academic content better from playing a game than from conventional media. The underlying research methodology involves comparing the learning outcomes of students who learn academic material by playing a game versus from a conventional lesson covering the same material. Mayer (2014, 2019) identified three subject domains in which game-based learning produced better learning outcomes than with conventional media (such as a slideshow lesson): science, mathematics, and second-language learning. For science learning, games were more effective than conventional media, with a median effect size of $d=0.7$ based on 16 experiments. For mathematics learning, games were more effective than conventional media, with a median effect size of $d=0.5$ based on six experiments. For second-language learning, games were more effective than conventional media, with a median effect size of $d=1.0$ based on five experiments. These emerging findings should be interpreted with caution in light of the methodological challenges in keeping the instructional content and method identical while varying the instructional medium (Clark, 2001). This handbook also contains media comparison research, which is aimed at determining whether games are a viable platform for promoting academic learning.

Overall, the research base on game-based learning is growing, as is demonstrated throughout this handbook. We now know something useful about what game features promote learning, what kinds of off-the-shelf games cause improvements in which kinds of cognitive skills, and what subject areas can be learned more effectively with games than with conventional media. This work has implications for theory (i.e., development of a theory of how people learn with media) and practice (i.e., designing effective digital games for learning), as described by Mayer (chapter 4 in this volume).

Design Elements of Game-Based Learning

There are a number of design elements for games that can be used to achieve the intended interactions with the learning content in a playful, motivating way. These include game mechanics, visual aesthetic design, sound design, narrative design, incentive system, and content and skills. We discuss these elements next, followed by a section that discusses the theoretical foundation for the design of these features.

Game Mechanics

Game mechanics refers to the essential gameplay; that is, the activity or sets of activities the player repeats throughout the game. In games for learning, we distinguish two types of mechanics: *learning mechanics*, which have primarily a learning goal and are designed based on learning theory approaches, and *assessment mechanics*, which have a diagnostic goal and are based on testing theory approaches (Plass & Homer, 2012). Many mechanics may have both goals (Plass, Homer, et al. 2013), and research has shown that the choice of mechanics has an effect on learning outcomes (Plass et al., 2012; Plass, O'Keefe, Homer, Case, & Hayward, 2013). Learning is facilitated when the game mechanics and the learning objectives are aligned (Plass et al., 2015). A more detailed discussion of the effects of game mechanics on learning can be found in Pawar, Tam, and Plass (chapter 14 in this volume).

Visual Aesthetic Design

Visual aesthetic design includes the visual design of the game environment, game characters, and, in some games, the player's own avatar. It also includes the information design in the learning content of the game, the visual design of cues and feedback, and the design of the tools and controls of the game. There exists a rich body of research on the design of each of these features, and a discussion of multimedia design principles for game-based learning can be found in Nelson and Kim (chapter 12 in this volume).

Sound Design

The sound design of a game may include a sound track, ambient sounds, and sounds associated with actions by the players or other characters. Sounds in games serve a motivational function, but they are also used for signaling and cueing that guide the player's attention. Sounds are also one of the design elements that induce different emotions in learners and therefore have the potential to affect learning via emotional design (Plass & Kaplan, 2016). Sound qualities in a game have been shown to have an effect on learning outcomes, as described by Pawar, Tam, and Plass (chapter 14 in this volume).

Narrative Design

The narrative of a game is the story line that is advanced through dialogues with other players, game characters, or agents, through voice-overs, or through cutscenes and in-game actions. Narratives can serve different functions, such as motivating play, providing context for the learning content, and connecting different game elements. Narratives in games differ from those of many other media in that they can be nonlinear, such that their progression depends on the learner's actions. Narratives have been shown to have an effect on learning outcomes, which is discussed, for example, in Dickey (chapter 11 in this volume).

Incentive System

The incentive system of a game includes a series of reward structures that are used to provide feedback and direct the player's behavior (Kinzer et al., 2012). These incentives can take on the form of point scores, experience points, coins, tokens, stars, badges, power-ups, trophies, loot, and other rewards. Rewards can be of an intrinsic nature, related to the gameplay and the learning objectives. In this case, a reward may consist of a new tool for exploration, a new piece of knowledge that unlocks a previously inaccessible part of the game, or a hint to be able to solve a learning-related problem. In contrast, extrinsic rewards can consist of stars, points, or loot that is not related to the core gameplay and the corresponding learning objectives. Incentive systems in games have been linked to learning outcomes, as described by Tam and Pawar (chapter 15 in this volume).

Content and Skills

A final element in the design of learning games is the learning content and skills that the game is designed to cover. The content of the game should determine all aspects of the game design, including the learning mechanics to be used, the visual design to be adopted, the narrative design, the incentive system design, and the sound design elements in the game (Plass & Homer, 2012).

Foundations of Game-Based Learning

This chapter is based on the idea that decisions about the design of digital games for learning should be based on a broad range of perspectives, including cognitive, motivational, affective, and sociocultural considerations. These decisions guide the design of all game elements described in the previous section. The Integrated Design Framework for Playful Learning (Plass et al., 2015), summarized in figure 1.4, incorporates these perspectives and connects them to the design elements of learning games, as well as the different types of engagement they can generate that lead to playful learning.

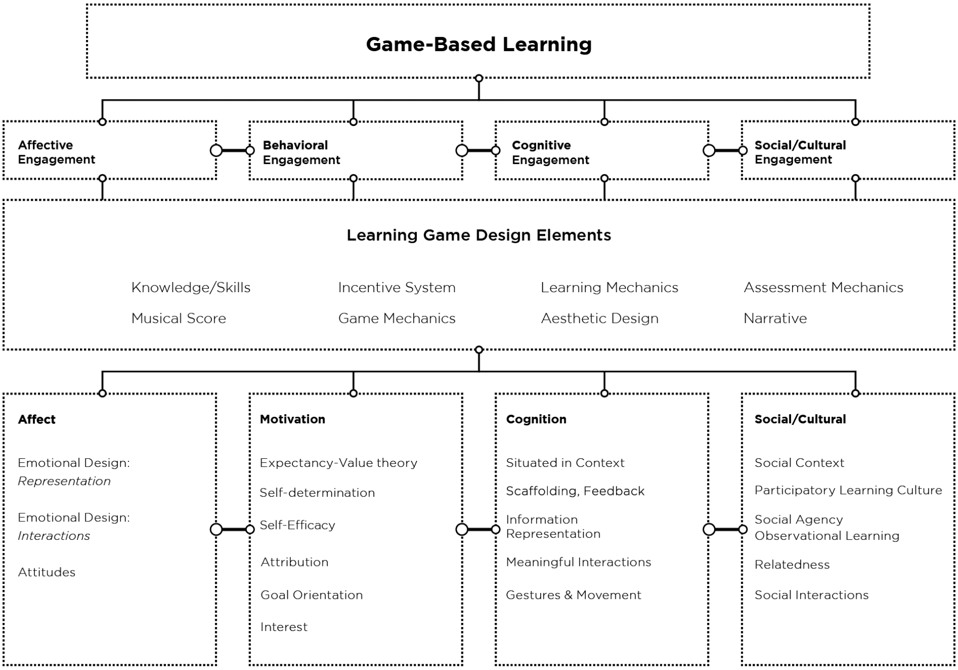

Figure 1.4
Integrated Design Framework for Playful Learning.

The design framework consists of three components that together result in playful or game-based learning. The lower part of figure 1.4 shows the four areas from which theoretical foundations for such games are drawn, which we will discuss in more detail. The middle section shows the game design elements that are used to implement these theories, which we discussed in the previous section. Finally, the top part of the model shows that, as part of learning from a game, players can engage on affective, behavioral, cognitive, and sociocultural levels. We discuss these forms of engagement next.

Types of Engagement in Game-Based Learning

One of the main arguments supporting the potential of digital games for learning is their ability to engage learners (Gee, 2007; Prensky, 2003). However, there are vast differences in what engagement in a game could actually mean. Take, for example, a player who is *grinding*; in other words, who is performing the same repetitive task in the same context, sometimes hundreds of times, for gameplay advantage. While such actions may be desired to build automaticity, no new skill is acquired, and no new knowledge is gained, yet the player looks very engaged. This is one of many examples of activities in games that make it useful to define the term “engagement” more specifically.

Our definition of engagement is based on a model of interactivity in multimedia learning advanced by Domagk, Schwartz, and Plass (2010). This model distinguishes four different types of engagement, which Schwartz and Plass (chapter 3 in this volume) describe in detail: behavioral, cognitive, affective, and sociocultural. *Behavioral engagement* involves specific physical actions, including swiping on a touch screen, gestures or button pressing with a virtual reality (VR) controller (Schwartz & Plass, 2014), or full-body movement when interacting with a motion-based interface such as Microsoft's Kinect. *Cognitive engagement*, in contrast, involves cognitive processing of information from the game in order to make meaning and construct mental models (Mayer, 2014). In many cases, cognitive engagement is most closely linked to the intended learning outcomes of a game (Mayer, chapter 4 in this volume). *Affective engagement* occurs when the learner has emotional responses, or develops emotional connections, to specific game elements. A typical example involves emotion experienced when interacting with game characters (Plass et al., 2019). Affective engagement can be used to increase cognitive engagement and thereby lead to increased learning outcomes (Schwartz & Plass, chapter 3 in this volume; Loderer, Pekrun, & Plass, chapter 5 in this volume). The final type of engagement is *sociocultural engagement*, which highlights social interactions within a game but also interactions within the emergent culture a game creates. This type of engagement can lead to increased cognitive engagement in support of learning (Steinkuehler & Tsaasan, chapter 7 in this volume).

Theoretical Foundations of Games for Learning

As summarized in table 1.2, we focus on four mutually supporting theoretical foundations of games for learning: motivational, cognitive, affective, and sociocultural.

Table 1.2

Four theoretical foundations of game-based learning

Name	Description/Basis
Motivational foundations	Theories describing motivational aspects of learning, such as self-determination theory (Ryan & Rigby, chapter 6 in this volume)
Cognitive foundations	Theories describing cognitive aspects of learning, such as cognitive theory of multimedia learning (Mayer, chapter 4 in this volume)
Affective foundations	Theories describing emotional aspects of learning, such as the control-value theory (Loderer, Pekrun, & Plass, chapter 5 in this volume)
Sociocultural foundations	Theories describing social and cultural aspects of learning, such as communities of practice (Steinkuehler & Tsaasan, chapter 7 in this volume)

Motivational foundations The ability games have to motivate players is the most frequently cited argument for using games for learning (Plass et al., 2015). Usually this argument comes from the observation that games for entertainment have been shown to be able to motivate learners to stay engaged over long periods (Steinkuehler & Squire, 2014). Game features that increase motivation include incentive systems, game mechanics, and activities that learners enjoy or find interesting. One aspect of a motivational feature is that games allow graceful failure, which means that rather than defining failure as an outcome to avoid, games often purposefully create failure during the first attempt at solving a task. This not only creates the necessary challenge to make tasks interesting, but also recognizes that failure can be a necessary step in the learning process (Kapur, 2008; Kapur & Bielaczyc, 2012; Kapur & Kinzer, 2009; Plass et al., 2010). Games lower the consequences of failure, thereby encouraging risk taking, exploration, and trying new things (Hoffman & Nadelson, 2010). Failure that is graceful can also provide opportunities for self-regulated learning, allowing players to monitor whether their strategies are effective and whether their goals have been achieved (Barab, Warren, & Ingram-Goble, 2009; Kim, Park, & Baek, 2009). Self-determination theory is also an important foundation for game-based learning applications, and is described in detail by Ryan and Rigby (chapter 6 in this volume).

Cognitive foundations Games have features that can enhance learner engagement, make tasks meaningful and relevant, and adaptively respond to learners' specific needs and conditions. It is of special interest that games can facilitate emotional, sociocultural, and behavioral engagement that can be used to promote learners' cognitive engagement, as described in Schwartz and Plass (chapter 3 of this volume) and Domagk, Schwartz, and Plass (2010). For example, a game may use a strong narrative to establish an emotional relationship between the player and a game character, which may then result in higher cognitive engagement when a problem needs to be solved involving this character. Higher cognitive engagement manifests as the learner engages in generative cognitive processing during learning, including selecting relevant information from the game, mentally arranging it into a coherent structure, and integrating it with relevant prior knowledge (Mayer, 2009, 2014).

Similarly, a game may foster social engagement by providing multiplayer options, and such social engagement may lead to higher cognitive engagement, either through competitive or collaborative play (Plass, O'Keefe, et al., 2013). Both sociocultural engagement and affective engagement can also make learning more meaningful and relevant for learners and situate tasks in ways that enhance learning (Lave & Wenger, 1991; Wenger, 1998; see also Steinkuehler & Tsaasan, chapter 7 in this volume). By analyzing various metrics in the game via game telemetry (e.g., user logs), games can also adaptively respond to learners' needs and therefore provide personalized interactions that enhance learning (Andersen, 2012; Azevedo, Cromley, Moos, Greene, &

Winters, 2011; Koedinger, 2001; Plass, Chun, Mayer, & Leutner, 2003; Plass & Pawar, chapter 10 in this volume; Steinkuehler & Duncan, 2008; Turkay & Kinzer, 2014). A more detailed description of the cognitive foundations of learning with games can be found in Mayer (chapter 4 in this volume).

Affective foundations Games can impact learners' emotions in many ways, such as by using the narrative, the aesthetic design, the game mechanics, or the musical score. The use of these features to induce emotions with the goal of enhancing learning has been described as emotional design (Plass & Kaplan, 2016). Research has shown that positive emotions not only broaden cognitive resources (Fredrickson & Branigan, 2005) but also enhance the learner's attentive state (Izard, 1993), serve as effective retrieval cues (Isen et al., 1978, 1987), and enhance decision making, creative problem solving, and related higher-level cognitive activities (Erez & Isen, 2002; Konradt, Filip, & Hoffmann, 2003). In addition to enhancing cognitive processing in various ways, emotions have also been shown to facilitate learning. For example, these enhanced learning outcomes have been linked to the induction of positive emotions through visual design elements such as shapes and colors of on-screen characters (Mayer & Estrella, 2014; Plass, Heidig, Hayward, Homer, & Um, 2014) but also to learners' initial confusion during learning (Craig et al., 2014; D'Mello & Graesser, 2014; Graesser, D'Mello, & Strain, 2014). Other studies have found that learning can be enhanced through empathetic agents that respond to the player's emotional state (Cooper, Brna, & Martins, 2000; D'Mello, Olney, Williams, & Hays, 2012; Lester, Towns, & Fitzgerald, 1998). Finally, enhanced learning has been found through high situational interest and resulting positive emotions induced by the game mechanics (Isbister, Schwekendiek, & Frye, 2011; Plass et al., 2012; Plass, O'Keefe, et al., 2013). A more detailed description of the affective foundations of learning with games can be found in Loderer, Pekrun, and Plass (chapter 5 in this volume).

Sociocultural Foundations

Games provide a broad range of opportunities for rich social interactions and can take advantage of important cultural variables during the learning process. In fact, some researchers argue that the communities created around games may be one of the most important aspects of game-based learning (Gee, 2007; Pearce, Boellstorff, & Nardi, 2011). Research on social aspects of games has revealed differences among single play, collaborative play, and competitive play, showing that a math game to automate arithmetic skills was more interesting to play when others were involved either as competitors or as collaborators but that the highest outcomes were achieved in the competitive version of the game (Plass, O'Keefe, et al., 2013).

A sociocultural perspective views games as systems distributed across people, players, and modalities (Steinkuehler & Tsaasan, chapter 7 in this volume). According to the sociocultural view, learning consists of interactions among these players, the construction of collective knowledge, and the application of this knowledge in the context of cultural norms and in relation to different identities (Squire, 2006). Sociocultural aspects of game-based learning are closely connected to cognitive, affective, and motivational factors. For example, cognitive and affective variables interact with the social and cultural contexts in which they occur (Turkay, Hoffman, Kinzer, Chantes, & Vicari, 2014). The power and promise of such approaches can be seen in citizen science projects such as *Foldit* and *EyeWire*, which use game-based approaches to leverage the help of large communities in solving scientific problems, such as protein folding and mapping the 3-D structure of neurons.

Additional sociocultural aspects of game-based learning, such as social aspects of agency, observational learning, and social interaction design, are discussed by Plass et al. (2015), and collaboration as the intervention, games as intact activity systems, and the reorganization of standard relationships of power in games are discussed by Steinkuehler and Tsaasan (chapter 7 in this volume).

Implications

Our review of the theoretical foundations of game-based learning, and the related theory of playful learning, has theoretical and practical implications, which we will discuss. We conclude this chapter by describing the cornerstones of a future research agenda on games for learning.

Theoretical Implications

It does not appear likely that a single theory will emerge that can guide the design of games for learning in general, since learning games have adopted many educational paradigms. Instead, we propose that a comprehensive view of game-based learning is required in order to take advantage of the potential of games. This view includes cognitive, affective, motivational, and sociocultural aspects. We summarized the foundations for these multiple perspectives, which are described in more detail in the chapters in part II, the theory section of this handbook. We believe that taking multiple perspectives (Goldman, Black, Maxwell, Plass, & Keitges, 2012), rather than a single theoretical approach, is essential for designing effective educational games because the broad range of design features requires a broad theoretical foundation.

Practical Implications

Our theory of playful learning has implications for the designers of games for learning as well as for educators and parents. For game designers, our approach suggests that the integration of multiple perspectives of learning is required if games for learning are to reach their full potential. The design foundations of games for learning are broad, spanning cognitive, affective, motivational, and sociocultural factors. This requires design teams with individuals who have expertise in these areas, and who can work collaboratively on game design.

We also propose that the design of games for learning involves clarity about a given game's function in learning process. This function could be to prepare future learning, learn new knowledge or skills, practice and automate existing knowledge or skills, or teach learning and innovation skills (Plass et al., 2015). Without a clearly defined function, a game's learning objectives and its learning mechanics are difficult to specify.

Our approach also describes how designers of learning games can leverage different types of engagement for games for learning. Because of the affordances of the design elements of games described earlier, learner engagement can be on a cognitive, affective, behavioral, or sociocultural level. Designers can use one type of engagement, such as affective engagement, to facilitate another type of engagement, such as cognitive engagement.

A final implication for game designers is that value-added research must often be conducted to guide design decisions. This is the case because, even though many theories already exist that can guide the design of games for learning, it may not be possible to base some design decisions on theory alone. This is discussed in the section on a research agenda for games for learning that follows.

For educators and parents, additional implications can be described. In the selection of suitable games for learning, educators and parents can evaluate games by reviewing whether the game includes a novel way to teach a subject or merely adds game features to an existing approach. Educators can also look for the balance of gameplay and interaction with the content, considering whether the game features support learning or possibly detract from achieving the learning objectives.

In general, one should ask why a game should be chosen to support learning of a particular subject for specific learners in a specific context? Why is a game a better way of learning about a given topic than another teaching medium—what does a game-based approach add that other approaches cannot accomplish? If these questions cannot be answered, it would be unclear why effort should be expended to design a game for the subject-area being considered.

Future Research on Games for Learning

Based on our review of the literature, we offer suggestions for future research on games for learning. In general, there are five different types of research on games that have been conducted (Mayer, 2014; Plass, Homer, Pawar, & Tam, 2018):

- *Usability research* is aimed at identifying problems with the overall design and its relation to content in ways that would prevent learners from using the game.
- *Design-based research* is aimed at iteratively refining the design of the game through the addition of different features (Hoadley, 2004).

- *Value-added research* focuses on the effectiveness of specific design features.
- *Cognitive, affective, motivational, and sociocultural consequences research* focuses on the effect of games for learning processes and outcomes.
- *Media comparison research* focuses on comparing learning with games versus learning with other media.

These types of research can be seen as a progression. Generally speaking, it is useful first to conduct user research and design-based or value-added research to investigate the effect of specific design features before conducting studies on the cognitive, affective, or motivational impact of games. In other words, before conducting research on the effectiveness of games for learning, these games first need to be optimized based on results from design research. Media comparison studies are useful to support policy decisions regarding the adoption of games for learning, providing politicians, school administrators, and teachers with the empirical evidence that justifies using games for learning on a larger scale.

More interesting for researchers and designers alike, however, is research on the effect of specific affordances of games for learning. This research aims to describe how games are a unique medium for education and serves to highlight the specific ways in which games can meet learning objectives in ways other media cannot. A final area for additional research is on using games to assess learning. This is discussed in more detail by Shute and Sun (chapter 20 in this volume).

Games are an intriguing medium for learning. Their complexity requires a comprehensive approach to their design as well as to the study of learning with them. It is our hope that this chapter provides useful insights that can guide researchers and designers alike to realize the potential of games for learning.

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2 Games as Playful Learning: Implications of Developmental Theory for Game-Based Learning

Bruce D. Homer, Charles Raffaele, and Hamadi Henderson

Theoretical Foundations of Playful Learning

Although it can be easy to recognize, play is notoriously difficult to define. In his influential book *Homo Ludens*, Johan Huizinga (1949) points out the inadequacy of attempts to describe and explain play from a purely behavioral or biological perspective. Huizinga argues that play goes beyond the "immediate needs of life" (p. 1); it has meaning, it has a sense, and, most importantly, it is fun! In the context of games for learning, Salen and Zimmerman (2005) build on Huizinga's work to argue that games need to be designed to allow *meaningful play*, which comes about not from the game itself but rather from the interaction of players, the game, and the context.

In the field of developmental psychology, there have been a number of attempts to create operational definitions of play. Krasnor and Pepler (1980) propose four criteria for identifying play: *flexibility*, *positive affect*, *nonliterality*, and *intrinsic motivation*. They suggest that "pure play" involves all these factors, with playlike behaviors involving some but not all the factors. Others point out that not all forms of play are flexible, and at least some involve negative affect (Smith, 2009). In their study of what defines play, Smith and Vollstedt (1985) include the four criteria of Krasnor and Pepler as well as an additional one, "dominated by means rather than ends" (from Rubin, Fein, & Vanderberg, 1983). Smith and Vollstedt found that nonexpert raters viewing videos of nursery school children's behaviors had high agreement concerning which behaviors were play but had less agreement about which of the five factors were involved. Smith and Vollstedt conclude that there is no single defining feature of play, but the more of the criteria are involved in a behavior, the more certain it is play. This is also the approach to understanding play—and playful learning—we take in the current chapter.

Developmental psychology has long recognized play as a most natural form of learning. Children engage in pretend play well before they have a fully developed theory of mind (Flavell, Flavell, & Green, 1987), and numerous researchers have argued that play is critical for children's cognitive, physical, social, and emotional development (Ginsburg, 2007; Hirsh-Pasek, Berk, & Singer, 2009—cf. Lillard et al., 2013). Both Jean Piaget and Lev Semyonovich Vygotsky wrote about the importance of play for the development of children. Each suggested that play supports children's learning, though they disagreed about some specific details (Piaget, 1962; Vygotsky, 1966).

Piaget's Theory of Cognitive Development

In his book *Play, Dreams and Imitation in Childhood*, Piaget (1962) addressed the role of play in children's cognitive development, particularly in regard to its support of symbolic abilities. Piaget viewed play as integral to, and changing along with, general cognitive development, suggesting that play becomes more abstract, symbolic, and social as children progress through different stages of development. According to Piaget, one way that play contributes to children's cognitive development is by activating schemas (i.e., basic units for organizing knowledge and behavior) in ways that transcend the present reality. For Piaget, play was primarily *assimilation*—the interpretation of environmental stimuli so that they are incorporated under the child's existing schemas.

Piaget (1962) claimed that the earliest forms of play were purely for "functional pleasure"—infants "play" by activating a sensory-motor schema in situations that are not originally tied to the schema, because it "feels good." For example, infants will activate their sucking schema to "nurse" on a fuzzy blanket to enjoy the sensation. In the earlier stages, play does not necessarily result in the creation of new cognitive structures, but it does serve a critical function in learning and development by allowing children to practice existing skills and knowledge, solidifying and refining their schemas (Pellegrini & Galda, 1993). As the complexity of children's play develops, so do the mechanisms involved in evoking schemas. Additionally, as older children's symbolic capabilities develop, they are able to extract and combine elements of existing schemas during play, creating new cognitive structures from these elements. For Piaget, then, although the primary role of play in cognitive development is in allowing practice of existing schemas, older children are also able to create new cognitive structures through play.

Vygotsky's Social Development Theory

Similar to Piaget, Vygotsky (1978) emphasized the importance of play. In fact, Vygotsky (1966) went so far as to suggest that play is "the leading source of development in preschool years" (p. 6). In contrast to Piaget, Vygotsky points out that often play is not "pleasurable" per se, but it does serve a purpose. Vygotsky argues that understanding play requires consideration of children's needs, wants, and motivations. A child's motivation for play changes with development—things that motivate an infant cease to have an effect on the motivation of a toddler and so forth. Through play, children are able to bridge the gap between the experiences they want and the experiences that are available. In this way, play serves to bring children to their *zone of proximal development* (ZPD).

Vygotsky defined the ZPD as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky, 1978, p. 86). In the ZPD, a child is given the opportunity to explore outcomes beyond his or her current abilities. Bridging the gap between children’s current abilities and their desired actions occurs when a more experienced learner and a child exchange cultural tools and the exchange is internalized by the learner (Schunk, 2012). This means that learners bring in their previous knowledge and fuse it with what is learned. Play creates the ZPD by allowing the child to subordinate the rules in a manner not possible in reality (Vygotsky, 1966). In play, children have the opportunity to plan and rehearse real-life activities in a sphere of imagination, allowing them to experience potential outcomes of their actions without the real-life costs. This allows children to break free of the constraints of the immediate situation. It also allows them to achieve more than they could otherwise. In other words, the constraints of play serve a scaffolding function to support the child in the ZPD. As Vygotsky (1966) wrote, “In play, a child is always above his average age, above his daily behavior; in play it is as though he were a head taller than himself” (p. 16).

Summary of Play and Learning in Developmental Theory

As is evident in this brief review, Piaget and Vygotsky each saw play as important for learning and development. Both emphasized play’s ability to allow children to reflectively break from the “here and now” as key to supporting learning. The theories differ somewhat in specific details, however. For example, Piaget characterized play as being motivated primarily by pleasure, but Vygotsky points out a much broader range of motivations for engaging in play. Also, for Piaget, play is an opportunity to reflect on and strengthen what has already been learned (e.g., by activating existing schemas in novel situations), while for Vygotsky play is a critical tool for learning new things. Piaget’s and Vygotsky’s ideas on play, though somewhat different, do point toward the same great potential of games as tools to support learning and development. Subsequent educational theorists, particularly those focused on early childhood education, have recognized the importance of play for the cognitive, physical, social, and emotional well-being of children (Ginsburg, 2007; Hirsh-Pasek et al., 2009—see Smith & Roopnarine, 2018). We now consider implications for learning through one particular type of play, games, starting with a brief history of games and learning.

A Brief History of Games and Playful Learning

The use of games to support learning has a long history. Even prior to the current interest in video games and learning, there was considerable research and theorizing on playful learning with nondigital games. A full review of this literature is beyond the scope of this chapter; however, we provide a few examples to demonstrate the breadth and importance of nondigital playful learning as well as to provide further context to understand playful learning with video games. We then briefly review the somewhat shorter history of video games for learning.

Nondigital Games and Learning

For quite some time, board games, which have been enjoying a recent resurgence in popularity (Graham, 2016), have been considered valuable educational tools. Gobet, de Voogt, and Retschitzki (2004) summarize over a century of work on various psychological topics in relation to board games, as well as contemporary research in artificial intelligence aimed at developing computers that play board games, arguing that this work has implications for understanding general human psychology. Zagal, Rick, and Hsi (2006) use the relative simplicity of board games to model collaborative mechanisms prominent in all games, including the often more complex (and sometimes more opaque) collaboration found in video games, such as massively multiplayer online games.

Linderoth (2013) outlines a framework for understanding gameplay, utilizing the perspective of ecological psychology. From this perspective, gameplay is seen as either perceiving, acting on, or transforming affordances. In other words, it is viewed as either noticing, acting in accordance with, or changing the environment and potential actions in the game. This framework is seen as “overriding the division” between digital and nondigital games and provides an example of how the work on nondigital playful learning gives insight into the conceptual basis for the use of play in learning with video games.

Video Games and Learning

Video games became the focus of psychological study almost as soon as they gained prominence in the 1970s and early 1980s with the unprecedented success of Pong, followed by the home console Atari VCS/2600 and various arcade games (Kent, 2010). As with any new technology, there was interest both in using video games and digital computers as research tools for studying psychology and in studying the effects of video games themselves. Early research covered an array of topics, such as children’s generosity in the context of video game playing (Barnett, Matthews, & Corbin, 1979), using participants’ electroencephalogram (EEG) readings as input for modifying paddles in a computer-generated Ping-Pong game (Brickett, Davis, Gabert, & Modigliani, 1980), and the effects of hypnotic suggestion on performance in a tennis video game (Baer, 1980).

Over time, research began to focus more on video games themselves. Malone (1981), drawing from previous studies that described what makes video games highly motivating and fun, developed a rudimentary theory of intrinsically motivating (i.e., motivating of its own accord) instruction using games. This theory was based on three categories: *challenge* (hypothesized to depend on goals with uncertain outcomes), *fantasy* (claimed to have both cognitive and emotional advantages in designing instructional environments), and *curiosity* (separated into sensory and cognitive components, and suggested to be able to be aroused by making learners believe their current knowledge structures are limited in various ways). In another study, analyzing motivation as it applied to the arcade game *Pac-Man*, Bowman (1982) included motivational explanations such as extrinsic means-ends motivational supports and intrinsic rewards.

In the early 1980s, Loftus and Loftus (1983) published their book *Mind at Play*, which was a serious and comprehensive examination of video games under the lens of psychological theory. They explained that video games are designed such that they manipulate schedules of reinforcement. This refers to the periods during which players' behaviors will be "reinforced" or rewarded. By using variable schedules of reinforcement (e.g., variable ratio or variable interval), the game staves off extinction of the reinforced behavior by intermittently rewarding players for their actions. Loftus and Loftus also analyzed the resolution of cognitive dissonance occurring in players who have to pay for their reinforcement, at least in arcades through inserting quarter after quarter to continue playing. Instead of making individuals not want to continue playing, payment may have *increased* their desire to play. This principle could easily be extended to many games that have come out since then, from one-time payment for home console games to internet-linked "micro-transaction" games that keep you paying to keep playing or to stay competitive. In addition, Loftus and Loftus analyzed video games under the lens of the information processing theory, describing at length how video games can support learning.

In this context, pioneering educational games emerged in the late 1980s and early 1990s, forming the foundation for future games for learning. The growing availability and popularity of personal computers in the early 1980s allowed the birth of educational software, including *The Oregon Trail*, *Number Munchers*, *Where in the World Is Carmen Sandiego?*, and *Reader Rabbit*. During this period, games were influenced by emerging best practices in teaching and learning of the time—they focused on active participation, open-ended learning, and constructivist learning principles. Invention, novel steps into unknown territory, was the norm, and even drill-and-practice games were infused with humor and creative energy (e.g., *Math Blaster*, which implemented a shooter game archetype for playing through its otherwise repetitive practice regimen). The fall of this early "Golden Age" of educational games came from a number of factors, including declining investment in innovation related to the shift from small innovative efforts to larger mainstream commercial enterprises; unsound and unsustainable infrastructure, including ineffective marketing and distribution channels; and unrealistic expectations placed on the new technology, with not enough consideration of the content being created and the context in which it was being used (Shuler, 2012).

Moving on in time, in the late 1980s and early 1990s, *SimCity* in its various incarnations (e.g., *SimCity 2000*, *SimCity 3000*, and *SimCity 4*) was a popular commercial game that was considered to have broad educational potential (Kim & Shin, 2016; Minnery & Searle, 2014; Tanes & Cemalcilar, 2010). On the cusp of eras, *SimCity* at its prime was old enough to have pre-Web 2.0-enhanced (e.g., pre–massively multiplayer online) capabilities but recent enough to have various elaborated gameplay and graphics that gave it affordances unavailable to earlier games. It is also interesting to note that the original *SimCity* had difficulty being supported by publishers, largely because of its groundbreaking open-ended nature. The game's creator, Will Wright, was often asked how he was going to "make it a game" (Keighley, 1999)—and in fact Wright (2007) has stated that he thinks of his games more as toys because they are for open-ended discovery. The uncompromising open-ended design of Wright's games ended up being a forerunner of future intensely open-ended games with educational potential, such as *Minecraft*.

The surging availability of high-speed broadband internet around 2005 led to new affordances in video games. Suddenly, video games with significant graphical and other data-intensive content could be played with other players from around the world, who could be either known or anonymous. *World of Warcraft* is the most famous example of this phenomenon, having reached seven million players by September 2006 (Harper, 2006). The educational possibilities of these *massively multiplayer online* (MMO) games were recognized by educators, who began to incorporate them into their classes (e.g., Delwiche, 2006). For example, using an immersive ethnographic approach, Nardi and Harris (2006) identified rich player interactions that allow diverse collaborative learning opportunities. Other research has since demonstrated the utility of MMOs for a variety of educational goals, including participatory cultures for civic education (Curry, 2010) and learning second languages (Kongmee, Strachan, Montgomery, & Pickard, 2011; Thorne, 2008). Although some concern was expressed (and continues to be expressed) about possible negative consequences of video games because of their sometimes violent, sexual, or immoral content, interest in the potential positive effects of video games has continued to grow.

One of the first, and most vocal, advocates of video games for education in the current era is James Paul Gee, who proclaims video games are "good for your soul" (Gee, 2005). In his influential book *Good Video Game + Good Learning*, Gee (2007) argues that video games embody best practices of learning, listing 36 "principles of learning" that are found in video games. Gee's work helped set the agenda for the current interest in the use of games for learning. There are now hundreds of researchers working on studying various aspects of games and learning, with many different academic societies and conferences to support this growing field. Apple's App Store contains around 200,000 apps that self-identify as being "educational" (CNET, 2018), with slightly larger numbers of educational apps found in the Google Play Store (42matters, 2019). Major software labels have also begun releasing educational versions of some popular games, such as *Assassin's Creed Origins—Discovery Mode*, *Minecraft.edu*, and *SimCity .edu*. Improvements in technology have also increased interest in the educational use of virtual reality (VR) and augmented reality (AR); however, more research is needed to explore ways to fully take advantage of the affordances of VR and AR (Akçayır & Akçayır, 2017; Freina & Ott, 2015; Tam & Pawar, 2019). We now consider, from a playful learning perspective, a few examples of how games can support learning in different domains.

Playful Learning in Different Domains

Game-based learning has been used successfully in many different domains for various school subjects. Many games and educational apps focus on science and math topics, but games have also been used to teach humanities, the arts, and languages, as well as to train educationally relevant cognitive skills. A few examples are given here to illustrate how a playful learning approach can be applied in different contexts.

Language Learning

Play can serve a critical role for learning both first and second languages. In first-language learning, children's parallel development of symbolic pretend play and language have been theorized as being linked, for example through development of the semiotic function (McCune-Nicolich, 1981). From a young age, children will engage in language play, which involves using language solely for pleasure rather than for a pragmatic purpose, such as to manipulate the environment or form social relationships (Cook, 1997). For second-language learners, language play includes language used in a practice or a fun situation that can provide a "safe space" for making mistakes while learning a language (Broner & Tarone, 2001).

There are several examples of video games supporting second-language learning. For example, players will join MMO game servers for languages that they are trying to learn, thus enacting a form of digital immersion. Not only is the game's preprogrammed content in the target language, but so are chats with other live players (Kongmee et al., 2011; Thorne, 2008;). In a systematic review, Peterson (2010) identifies several studies that investigate games for second-language learning, whether they were intended for this purpose or not. Examples include giving directions in a second language to a player piloting a simulated helicopter toward a target, playing the life simulation game *The Sims* in a second language, and playing a game implemented by the US military that trained servicepeople in Iraqi Arabic prior to their being deployed to Iraq. A more detailed discussion of the use of games for learning a second language can be found in Reinhardt and Thorne (chapter 17 in this volume).

Mathematics and Science

Math and science have been the focus of much game development and research, in part because of the great emphasis placed on science, technology, engineering, and mathematics (STEM) in the standard school curricula (Porter, McMaken, Hwang, & Yang, 2011). The potential of play to support STEM learning is found even for the youngest students. For example, block play in preschoolers has been found to predict subsequent academic achievement in mathematics (Wolfgang, Stannard, & Jones, 2001). More generally, play with spatial toys such as blocks, puzzles, and shape games supports the development of spatial skills and is related to school readiness, particularly for STEM areas (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). Manipulatives generally can be useful and fun, but in order to be useful learning tools and not a distraction, they need to be effectively incorporated into classroom lessons. Otherwise, they can become just a break from real learning (Moyer, 2001). Virtual manipulatives, which can have even greater affordances than their physical counterparts, have the potential to provide even better support for learning (Steen, Brooks, & Lyon, 2006).

Given the benefits of virtual manipulatives, it is not difficult to see how video games can be useful for learning math and science. Devlin (2011) claims that learning math from books inhibits learners' ability to develop mathematical thinking, because it focuses heavily on mastering skills and not concepts. He argues that video games provide the ideal environment for learning mathematics because they situate math learning in context, making it easier for learners to understand the math concepts and the situations in which they would be applied. The learning environment available in video games is malleable in a way that allows educational designers to embed mathematical principles in the environment and experience contextualized learning. Video games can give numbers "meaning," which motivates players to develop mastery in order to succeed in the game.

A playful learning approach can also be useful for science. For example, Plass et al. (2012) investigated the effectiveness of using a sequence of chemistry learning simulations in both rural and urban high schools. Their results indicated that, given effective implementation, the simulations improved chemistry learning. Although not studying video games per se, simulations, like video games, provide a safe environment in which scientific experimentation can occur (Salen & Zimmerman, 2004). In a review of work on video games and STEM learning, Mayo (2009) points out that the data are sparse and mixed but generally support the claim that well-designed games can be effective tools for learning STEM.

Beyond development of skills and knowledge, playful learning can also support changes in attitude toward math and science. Henniger (1987) suggests that childhood play provides excellent opportunities for developing a positive attitude toward science as well as a chance to teach foundational STEM concepts. An example of this comes from the RAPUNZEL project (Plass, Goldman, Flanagan, & Perlin, 2009), which developed and evaluated an online game to teach basic programming skills to girls. Plass et al. (2009) found that, after playing the game, sixth-grade students had significant improvements in a number of attitudinal measures, including self-efficacy, self-esteem, computer self-efficacy, and programming self-efficacy. A more detailed discussion of the use of games for learning science, mathematics, engineering, and technology can be found in Klopfer and Thompson (chapter 16 in this volume).

Social Studies and History

Video games have a number of affordances that allow them to support learning in social studies and history, including strong narratives and interactivity. Both are evident in the *Civilization* series of games, which have been used to teach social studies and history (e.g., Pagnotti & Russell, 2012; Squire, 2004). Squire (2004), who studied high school students using *Civilization III* in a unit on world history, found that the game was able to engage the students in unique ways, supporting conceptual understanding of history. Similarly, in their study of a high school history class using *Civilization III*, Lee and Probert (2010) found gameplay was complex. They note that a certain degree of creativity is required for teachers to figure out how to use the game within the constraints of standard US history curricula. Therefore, they suggest situating students' game experiences in rich classroom discussions and specific nongame activities as ways to enhance learning.

McCall (2013) points to a number of features that can make historical simulation games, such as *Civilization*, *East India Company*, and *Total War*, good tools for teaching history, although expressing concerns about issues in these games, such as oversimplifications, too much access to power and information, and quantification bias (i.e., the need to represent even ambiguous and abstract factors as precise, numerical values). Nonetheless, these types of games present players with historically relevant *problem spaces*, or visual, aural, and spatial worlds in which meaningful decisions must be made to solve problems, and can help students understand the complex, interrelated systems involved in history.

Development of Cognitive Skills

There has been great interest in using video games to develop specific cognitive skills. For example, a series of studies (Bavelier, Green, Pouget, & Schrater, 2012; Bediou et al., 2018; Green & Bavelier, 2006a, 2006b) have shown that action video games (i.e., first- and third-person shooter games) can enhance a variety of perceptual and cognitive functions, including skills related to learning. For example, Green and Bavelier (2006a) first demonstrated that participants who regularly played action video games performed significantly better on a number of measures of visuospatial attention. Then, through a randomized controlled experiment, they demonstrated that participants who were not regular players of action video games had significantly better visuospatial attention than a control group after 30 hours of playing over an eight-week period.

A related area where there has been considerable interest is the use of video games to develop executive functions (EFs). Broadly, EFs are a set of interrelated cognitive skills required to plan, monitor, and control cognitive processes while performing a task (Miyake et al., 2000). There is growing empirical support for the relation between EF and a number of important outcomes, including academic achievement (Best, Miller, & Naglieri, 2011; Blair & Razza, 2007), so there is considerable interest in how best to support the development of EF, including through video games (Diamond & Lee, 2011).

Although some reviews have found only negligible effects of video game play on EF (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013), other studies have found that video game play can enhance certain EF abilities (e.g., Parong et al., 2017). One possible explanation for this discrepancy is that most studies on training EF use either "gamified" versions of existing EF measures or commercial games that were not intended to train EF. Homer, Plass, Raffaele, Ober, & Ali (2018) argue that the brain-training "games" lack essential game features, such as being engaging and motivating, while the commercial games may be engaging but do not require enough use of the specific skill being trained. Studies that have found significant effects have tended to use custom-built games that are genuine games requiring players to use the specific skill being trained (e.g., Anguera et al., 2013; Homer, Plass, et al., 2018; Parong et al., 2017).

In our own work, we have also found promising results with video games that were developed with the specific intention of training EF skills. For example, in a recent study (Homer, Plass, et al., 2018), we found that playing *The Alien Game*, a video game developed explicitly to train the EF skill of shifting (i.e., the ability to flexibly adjust to changing demands or priorities), significantly improved this ability in high school students after a six-week intervention of 20 minutes of gameplay per week. In another study with *The Alien Game*, Parong et al. (2017) found that college students had significant improvements in the EF skill of shifting compared to a control group after two hours of play over four sessions. Following up on this work, we have shown how a number of game elements related to playful learning significantly enhance the effects of EF games, including making the game adaptive to enhance the challenge for players (Plass, Homer, Pawar, Brenner, & MacNamara, 2019), increasing the emotional engagement of game characters (Plass et al., 2019), and increasing the engagement of gameplay through the use of emotional design (Homer et al., 2019).

Similar results have been found in studies to improve basic cognitive skills in the elderly. In a randomized controlled study with 70-year-olds, Basak, Boot, Voss, and Kramer (2008) found that that just under 24 hours of training with a real-time strategy video game resulted in improved measures of game performance and of some cognitive tasks (task switching, working memory, visual short-term memory, mental rotation). More recently, Anguera et al. (2013) found that elderly adults (aged 60–85 years) demonstrated gains in skills related to cognitive control after playing a game, *Neuroracer*, that was specifically designed to train these skills. Improvements in working memory and sustained attention were also found. In fact, the trained elderly participants attained levels of reduced multitasking costs beyond those achieved by untrained 20-year-old participants, with gains persisting for six months. Thus, video games have been shown to have utility for improving cognitive functions of the elderly.

These examples of design-based research on games for learning in particular domains show how playful elements in games are based on learning theories and relevant psychological theories. We now consider key learning theories and theoretical concepts relevant for understanding playful learning.

Learning Theories and Playful Learning

In their review of game-based learning, Plass, Homer, and Kinzer (2015) point out that no single learning theory can be applied to all educational games. Building on a "general learning model" proposed by Gentile, Groves, and Gentile (2014), Plass et al. (2015) suggest a "simple model" of game-based learning common to all games, which includes a *challenge*, a *response*, and *feedback*. The learning theory (or theories) that informed the design of any game for learning will be evident in the specific challenges, the kinds of responses made available, and the type of feedback given to the learners. In the following subsection, we review relevant learning theories and key concepts related to playful learning and how they apply to educational games.

Behaviorism

As mentioned in the early analyses of Loftus and Loftus (1983), the principles of behaviorism go a long way in explaining the appeal of video games to players and educators. B. F. Skinner's operant conditioning posits that behaviors are driven by rewards and punishments, with rewards reinforcing behaviors and punishments discouraging them (Skinner, 1971). In video games, players are afforded ample opportunities for their actions to be reinforced. Successful completion of diegetic objectives in games provides players with rewards of leveling up, progression of the story, or receiving in-game items. Players can also receive trophies that are visible on their gaming networks for all their peers to see. Failure to master game controls or complete objectives typically results in the punishment of having to repeat portions of the game, a consequence that players aim to avoid. The consequences of players' actions (or inactions) are often immediate in video game environments. Players can easily link their gameplay to the consequences that follow. Games employ both continuous and intermittent reinforcement schedules. Continuous reinforcement schedules provide reinforcement after every successful completion of the desired behavior, whereas intermittent reinforcement schedules only offer reinforcement at certain periods or after a certain number of desired behaviors. The skillful incorporation of these schedules helps motivate players to continue playing and persevere through challenges presented in the game. The schedules also encourage the player to return to the game after time away. Given the behaviorist principles inherent in video games, it is clear to see how games can serve as tools for learning, in that they engender consistent participation and engagement from the player over long periods—behavior that is necessary for successful learning.

Information Processing Theory

Traditional information processing theory (e.g., Schunk, 2012) also applies to understanding the experience of playing video games. From this perspective, video games send large amounts of stimuli, from enemy projectiles to on-screen maps, to the player's *sensory register*. Through attention, players select the most relevant stimuli for further processing in *short-term memory*. It is in short-term memory that players coordinate the information received from the sensory register and mobilize their skills in pursuit of the game's objectives. Repetition of this process allows players to undergo cognitive change, with new information being encoded into *long-term memory*. As a result, learning takes place as players develop proficiency in navigating the game's objectives.

Baddeley (1992) presents a model of working memory that involves two storage systems, a *visuospatial sketchpad* for visual and spatial content and a *phonological loop* for auditory (mainly verbal) content, as well as a *central executive* that controls the limited capacity of the subsystems. The *episodic buffer*, which serves as a "temporary multidimensional store" linking the subsystems, was added to the model later (Baddeley, Allen, & Hitch, 2011). Because video game output is split almost entirely between moving images and audio or verbal content, information is sent to both domain-specific subsystems proposed in this model of working memory, which facilitates processing of the information. Ke (2009), for example, proposes that the multisensory information presented in video games facilitates schema construction by offering learners a "ready-made," explicit representation of complicated concepts, which is an ideal form of external support for constructing internal mental models.

Building on Baddeley's model of working memory, Mayer (2002, 2009) proposed the *cognitive theory of multimedia learning*, which argues that splitting information between the visual and auditory channels enhances learning by not overwhelming the limited capacity of either channel. This allows learners the cognitive resources to actively filter, select, organize, and integrate information into long-term memory. Video games not only take advantage of auditory and visual channels but can also use other pathways to convey information, such as haptic feedback given by controllers (e.g., "rumble" features). Touch is also the primary modality through which input is given, either through the joystick and buttons of traditional game controllers, the motion tracking of the Wiimote controllers or Microsoft Kinect camera, or touch-screen controls found with the WiiU gamepad or the many smartphone or tablet games. By splitting input and output of information across multiple modalities, video games are being consistent with principles proposed in Mayer's multimedia theory of learning. A more detailed discussion of cognitive processes in learning from games can be found in Mayer (chapter 4 in this volume).

Constructivism

Constructivism posits that knowledge is constructed by learners themselves rather than being copied verbatim into their minds (Duffy & Cunningham, 1996). The theories of Piaget and Vygotsky were instrumental in the founding of cognitive constructivism and social constructivism, respectively (Powell & Kalina, 2009), so their ideas on the value of play in learning, already covered here, also serve as a foundation of how constructivism operates in playful learning theory (for example, as being useful for assimilation and creating the ZPD). In addition, video games have been identified as having particular utility by enabling situated learning for players inside virtual worlds (Shaffer, Squire, Halverson, & Gee, 2005). This represents the successful implementation of a constructivist learning method of building knowledge in the same (or similar) context as it would later be applied. Therefore, play, including play with video games, has great potential to allow constructivist learning to take place.

Research on video games, through the lens of social cognitive theory, tells us how deep dynamics of society and narrative structures may play out uniquely for video games, as opposed to older media, such as television and film. Sherry, Lucas, Greenberg, and Lachlan (2006), in their analysis of video game uses and game preference, connected Bandura's (1994) social cognitive theory with video game play. They argue that video games operate differently from the centuries-old socialization-through-folklore storytelling mechanism of television, such that the audience may not seek role models from video games the way they do from television. These findings are striking, particularly given that by 2006 many video games already had highly developed storytelling features (e.g., dramatic cutscenes and enacting of important choices), with advanced character development and involving narratives (e.g., *The Legend of Zelda: Ocarina of Time*; *Star Wars: Knights of the Old Republic*; and *Final Fantasy VII*). The findings by Sherry et al. indicate a further way that video games can support learning on a whole new level.

Social constructivism focuses on knowledge being socially situated and constructed through interactions with others. Contrary to popular portrayals, gameplay is often a social activity, with over 70% of gamers reporting playing with a friend, either cooperatively or competitively (Entertainment Software Association, 2012). Consistent with a social constructivist approach, video games do bring people together through constructing and sharing knowledge. Gee (2007), for example, writes about "affinity groups" that form online around specific games, where people share information as a way of learning together. Another example comes from Squire (2008), who discusses how professional role-playing games are important for learning because they situate learners in the roles of engineers, biologists, or forensic scientists in the process of solving complex scientific problems. This merger of sociocultural and constructivist learning principles leaves the learner, from a sociocultural learning perspective, set up with a role to inhabit with practice of the problem solving, gameplay, and argumentation that occurs in the service of that role. A more detailed discussion of sociocultural issues in learning from games can be found in Steinkuehler and Tsaasan (chapter 7 in this volume).

Key Concepts and Applications of Playful Learning

All the learning theories reviewed here can inform the design of effective games for learning—often with several theoretical approaches being found in the same game. For example, a single game may use a cutscene involving narration (audio) presented with an animation (visual) to explain a new concept (i.e., splitting information between the visuospatial sketchpad and phonological loop, from *information processing theory*). If players correctly solve a problem using that information, the game could give points and play a pleasant sound (i.e., contingent reinforcement and operant conditioning, from *behaviorism*). The players may then have to explain and share their solution with other players, who work together to solve an even more complex problem in the game (i.e., integrating information and collaborative learning, from *cognitive constructivism* and *social constructivism*). In this way, design of effective educational games should be *polytheoretical*, embracing concepts from multiple theories in order to enhance learning and playfulness. In the following subsection, we review several key theoretical concepts from learning theory and game design that are relevant for playful learning in video games.

Engagement

From very early on, researchers were intrigued by the high level of engagement shown by video game players (e.g., Loftus & Loftus, 1983; Malone, 1981). It is often this high level of engagement that has made educators argue that games can be good tools for learning (e.g., Gee, 2007; Plass et al., 2015; Prensky, 2006). We have already described a number of the features that make games engaging, including variable reinforcement schedules, appealing sensory input (visual and auditory), cognitive challenge, and social connection. When playing a good video game, players will often describe being in a deeply immersed state, which is part of the educational potential of video games (Hamari et al., 2016).

Csikszentmihalyi and colleagues (Csikszentmihalyi, 1997; Nakamura & Csikszentmihalyi, 2014) have conducted considerable research on being in a deep state of engagement, which has been described as being in a state of *flow*. When in a state of flow, individuals are deeply and effortlessly involved with their current activity, not thinking about other things, such as the hassles of daily life. In this state, there is a sense of control over one's actions, a reduced sense of self-awareness, and often a distorted sense of time. A flow state is typically induced when someone is faced with challenges that stretch, but do not overwhelm, their abilities, and there are clear goals, with immediate feedback indicating progress. Because games can meet all the required criteria, they have been identified by Csikszentmihalyi (2014) as being an ideal medium for inducing a state of flow.

In educational settings, flow states are important because they can alleviate the burden of self-conscious awareness, which can hinder learning (Csikszentmihalyi, 2014). By reducing self-awareness, learners can focus their attentional resources on processing important educational information. Additionally, the flow state experience serves as motivation to repeat tasks that provided the experience (Csikszentmihalyi, 2014). With that in mind, experiencing flow through playful learning, as can happen with highly engaging educational games, can make additional cognitive resources available for learning and can motivate learners to persevere through challenging or repetitive tasks.

The term engagement describes the "active and focused investment of effort" (Schwartz & Plass, chapter 3 in this volume). Schwartz and Plass define four types of engagement in games: *behavioral engagement*, the player's actions, gestures, and movements in interactions with the game; *cognitive engagement*, the player's processing of information, planning, and decision making; *emotional engagement*, the player's emotional response to the game; and *sociocultural engagement*, the player's social interactions with other players. Consideration of these different types of engagement allows a more nuanced understanding of the effectiveness of a game. For example, if players are engaged behaviorally but not cognitively, then learning is less likely. In contrast, if the game engages players emotionally, and this results in cognitive engagement, then learning is more likely (Schwartz & Plass, chapter 3 in this volume).

Motivation

There are many factors that can motivate learners to play an educational video game. From the perspective of playful learning, games are motivating because they meet the "needs, wants and desires" (Vygotsky, 1978) of players, which can simply be "functional pleasure" (Piaget, 1962) but can also include motivations that are more complex, such as the need to learn, the desire for cognitive challenge, or the desire for social connection.

Abraham Maslow's hierarchy of needs (Maslow, 1943) provides a good starting point for thinking about motivations. Maslow theorized a pyramid of needs that drive motivation, with more basic needs (e.g., physiological and safety needs) forming the base and more advanced, complex needs forming the top (e.g., need for esteem and self-actualization). As basic needs are satisfied (e.g., the need for water, air, or sex), higher-order needs become important, and their fulfillment is sought (e.g., the need for respect in one's community, the need for personal growth and fulfillment). In the context of video games, Siang and Rao (2003) rewrote Maslow's hierarchy of needs to explain players' motivations. This model consists of the following "needs," ordered from most basic to highest order:

1. *rules*—the need to know the basic rules of the game;
2. *safety*—the need to know information that will allow players to stay in the game long enough to win;
3. *belongingness*—the need to feel comfortable with the game and to know that winning is possible;
4. *esteem*—the need to be in full control over the game;
5. *knowledge and understanding*—the need to find greater challenges and learn more about the game (e.g., different strategies, hidden items);
6. *aesthetic*—the need for good graphics, visual effects, and other aesthetics;
7. *self-actualization*—the need to "play God" in the virtual world (i.e., be able to do anything that conforms to the game's rules).

When considering educational games, additional consideration is needed for the specific motivations involved in learning.

A key distinction has been made between *intrinsic* and *extrinsic* motivations for learning. Activities are considered intrinsically motivated when they are done for their own sake, and extrinsically motivated when done for external, instrumental reasons, such as getting a reward (Eccles, Wigfield, & Schiefele, 1998). Generally speaking, intrinsic motivations lead to better educational outcomes, particularly when considered over time (Eccles et al., 1998). With video games, players will sometimes play for the sake of receiving external rewards, such as trophies or loot (i.e., showing extrinsic motivation), but are often motivated to play for the enjoyment of the actions in the game itself (i.e., showing intrinsic motivation). In a review, Dondlinger (2007) found that effective video game design considers both intrinsic and extrinsic motivations for play. With games designed for learning, motivations become even more complex, because of the possibility that there are different goals for gameplay and for learning. In light of this, Plass et al. (2015) argue for the need to keep *game mechanics* (i.e., the actions done within a game) and *learning mechanics* (i.e., activities that support learning in the game) closely aligned, which can help keep students from "gaming the game" by finding ways to succeed in the game without learning the intended educational content.

Expanding on the basic intrinsic/extrinsic dichotomy, *self-determination theory* (Deci & Ryan, 1985) considers the natural and intrinsic needs that drive us. This includes the component needs for *competence*, *autonomy*, and *relatedness*, which refer respectively to developing mastery, personal agency, and social connections to others. Ryan, Rigby, and Przybylski (2006) used self-determination theory to investigate motivation for video game play and found that autonomy, competence, and relatedness independently predicted enjoyment and future game play. In video game environments, players are typically offered agency to complete goals (i.e., autonomy), are supported and allowed to retry until they complete their goals (i.e., competence), and will often either work collaboratively or share their accomplishments with other players (i.e., relatedness); see Ryan and Rigby (chapter 6 in this volume) for more details.

Related to intrinsic and extrinsic motivation is the notion of *achievement goals* for engaging in learning activities. Broadly speaking, learners have been classified as having either a *mastery goal orientation*, which focuses on learning new skills, mastering material, and learning new things, or a *performance orientation*, which focuses on maximizing favorable evaluations of competence (Dweck & Leggett, 1988; Elliot, 2005). Mastery goal orientation has generally been found to be predictive of more adaptive patterns of motivation and learning (Midgley, Kaplan, & Middleton, 2001). In the context of video games, mastery goals would be related to acquiring new skills (i.e., being able to do new things) within the game, while achievement goals are related to just gaining points, completing levels, or acquiring “trophies.”

Biles, Plass, and Homer (2018) investigated game design, motivation, and learning outcomes in a geometry game for middle school students. The authors compared different versions of the game that incorporated one of three badge implementations: performance badges, mastery badges, or no badges. In the *performance* condition of the game, students received digital badges that encouraged performance goals by marking achievement in relation to the performance of peers (e.g., “Congratulations! You were faster than most other players”). In the mastery condition, students received badges that encouraged mastery goals (e.g., “Congratulations! You mastered the triangle rule!”). Overall, learning outcomes for students in the performance badge condition were better than for students in the mastery badge condition, but this effect was mitigated by significant interaction between badges and students’ *situational interest*, which was motivation for learning from the game. Students with higher situational interest had better learning outcomes with mastery badges. This finding is an example of how game features can have different effects for different learners and argues for the need to understand how best to personalize the learning experience.

Individual Differences and Adaptivity

Another aspect of digital technologies, including games, that has excited educators is the ability to create a personalized learning experience. In spite of this potential, there has been very little agreement over what personalized learning really means, with most learning systems focusing solely on whether a test question was answered correctly (Means, Bakia, & Murphy, 2014). As a way of thinking about personalized learning in broader terms, a *taxonomy of adaptivity* has been proposed by Plass (2016, chapter 10) that considers *cognitive*, *motivational*, *affective*, and *sociocultural* domains. Although there are many factors within each of these domains that are important for learning outcomes, there is still a paucity of research on how best to adapt to individual differences within the different domains (see also Plass & Pawar, chapter 11 in this volume).

In an examination of adaptivity in video games and related digital environments, Kickmeier-Rust and Albert (2010) identify three broad categories: *presentation of materials* (look and feel), *curriculum sequencing* (to match a learner's preferences, goals, prior knowledge, and other attributes), and *problem-solving support* (giving hints, tips, strategies, and other aids if a learner is struggling). They argue that because video games can consistently, and nonevasively, evaluate players, educational video games should be designed to intelligently monitor, interpret, and respond to learners' behavior in order to maintain engagement and motivation, a process they call *micro-adaptivity*. To be successful, this type of micro-adaptivity requires educationally relevant assessments in multiple domains that then feed back into the game, but very little work has been done to study this approach (see Homer, Ober, & Plass, 2018).

On a broader level, one area where individualization has met with some success is in creating learning games to support populations with special needs. In an early example of this, Masendorf (1995) found that children11 to 13 years old who had been diagnosed with a learning disability (LD) were able to improve their two- and three-dimensional spatial abilities by playing *Tetris* and *Block Out*, but this effect did not transfer to a test of general intelligence. In a more recent study, Marino et al. (2014) examined the benefits for students with LD of supplemental materials, including educational video games and alternative text, having a design informed by Universal Design for Learning (UDL) guidelines. Over the course of a year, students with LD demonstrated heightened levels of engagement, though they did not achieve greater scores on traditional tests in units that included the UDL-informed supplemental materials. The authors conclude that the supplemental materials, including educational games, did benefit learning by providing students with multiple means of representation and expression but that alternative assessments were needed to better measure learning outcomes. This finding also suggests that video games may have various learning benefits that are not tapped by traditional means of assessment and argues that more assessments be built directly into games for learning (Homer, Ober, & Plass, 2018; Shute, 2011; Shute & Chen, 2019).

Affect and Emotional Design

As a final area of interest, we consider affect and emotional design. As mentioned in the beginning of this chapter, one of the ways that play is seen as supporting learning and development is by allowing space for activities without "real-life costs" (Vygotsky, 1966). This is also true of video games, where players are more inclined to take risks because the cost of failure is significantly lower than the cost of failure in a real-world setting (Gee, 2003). In traditional learning environments, students may be given only one opportunity to perform, with failure resulting in harsh penalization (e.g., lower grades, denied admission into schools). In contrast, failure in a playful learning environment of games typically means replaying a sequence with the added insight from previous failures. In this sense, failure is not an undesirable outcome but rather is expected and often considered necessary for the learning process (Kapur, 2008; Plass et al., 2015). By designing *graceful failure* into games, negative feelings associated with not succeeding are reduced and persistence is encouraged. The chance for multiple attempts at success also provides players with an opportunity to regulate their own learning, as they are able to set goals, monitor their achievement of these goals, and assess the effectiveness of strategies used in their attempt to achieve their goals (Kim, Park, & Baek, 2009).

Within education, there is growing interest in understanding the role of emotions in learning. With the *control-value theory of achievement emotion* (CVT), Pekrun (2000) presents a framework for understanding emotions experienced by learners and how these emotions affect the learning process. For example, positive emotions, such as enjoyment, are believed to give learners a sense of autonomy and of developing an intrinsic value of learning. The CVT is one of the foundations of the integrated model of emotional foundations of game-based learning described by Loderer, Pekrun, and Plass (chapter 5 in this volume). Plass and Kaplan (2016), in their *integrated cognitive-affective theory of learning with media*, argue that emotions play a critical role in selecting, organizing, and integrating visual, verbal, and auditory information to create integrated mental models. Building on this, Plass and his colleagues (Plass, Heidig, Hayward, Homer, & Um, 2014; Um, Plass, Hayward, & Homer, 2012) have proposed an *emotional design* approach for creating digital learning environments, including simulations and games, in which the design of the game itself can induce emotions that will enhance learning (see also Pawar, Tam, & Plass, chapter 14 in this volume). Plass et al. (2014) identify at least two methods of inducing emotions with digital learning materials: by the way in which informational materials are represented, and through the use of playful game mechanics. Plass and his collaborators (Plass et al., 2014; Um et al., 2012) have found positive learning outcomes when digital learning environments represent information in ways that induce positive emotions (e.g., by using round shapes and warm colors), but more work is needed to investigate the effects of playful game mechanics on learning.

Conclusions and Implications

The goal of this chapter has been to explore how a playful learning perspective can further our understanding of the ways in which video games can support learning.

The field of developmental psychology has long recognized the importance of play, seeing it as not only the most natural way of learning but also as a central mechanism of cognitive development. A key feature of play is that it is intrinsically motivating—we play for the sake of play! Also essential is the safe space created by play—risks can be taken with minimal consequences, and graceful failure is allowed. In the context of games, Salen and Zimmerman (2004) talk about the space where games are played as being a *magic circle*, with its own set of rules, values, and logic that is separate from reality. To be an effective tool for learning, the design of a magic circle as an educational game needs to be informed by learning theories. Although educators often have a specific theoretical stance, playful learning is consistent with multiple theories, and, arguably, a polytheoretical approach is needed to fully understand game-based learning. From the review of educational video games, it is clear that the approach to learning within any game is a product of dominant learning theories of the era as well as the affordances of the specific platform used for the game. Finally, a summary of key concepts from learning theories makes it clear that they are compatible with a playful learning perspective and can be incorporated into effective games for learning.

Based on the preceding review, the following key principles of playful learning emerge:

- *Playful learning is intrinsically motivating*. Although the motivation for play may be for fun and pleasure, other motivations, including challenge and self-actualization, are also essential.
- *Playful learning depends on a break from reality.* For learning to be playful, there must be opportunity for exploration and graceful failure with minimal real-world consequences, as in the “magic circle” of games.
- *Playful learning requires a polytheoretical approach*. Not only is playful learning compatible with multiple learning theories, but effective games for learning will often embrace concepts from multiple theories in order to enhance learning and playfulness.
- *New technologies provide new opportunities for playful learning.* Although the fundamentals of play are consistent, the affordances of new technologies provide new opportunities for game-based learning.
- *Playful learning requires an integration of play and learning.* In effective games for learning, game mechanics and learning mechanics match, meaning in-game activities are both fun and support learning.

By applying the concept of playful learning, we can realize educational experiences in digital games that may go beyond even what was envisioned by Vygotsky and Piaget in supporting the cognitive development and learning of children.

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3 Types of Engagement in Learning with Games

Ruth N. Schwartz and Jan L. Plass

Introduction

The power of games for education is often described in terms of their potential to enhance learning by engaging users. In this chapter, we investigate the idea of *engagement* in the context of games for learning: How do we define engagement? What is the importance of engagement in learning? How has engagement in games typically been observed and measured? We then examine the idea of different types of engagement and propose an approach to describing and operationalizing these categories. Finally, we discuss practical and theoretical implications of the current research and suggest directions for future investigation.

Engagement in Games

Carefully aiming an angry bird at a pig castle; watching closely as the futuristic narrative of a new game unfolds in a cutscene; teaming up with other clan members to execute a raid on a virtual town; crying over the loss of a beloved companion on a journey through treacherous lands—each of these is an example of engagement, of how an individual may be involved with a game. However, these examples vary widely with respect to the user's activities: watching and processing; planning and taking aim; discussing and strategizing; developing an emotional investment. It is clear that engagement can encompass a diverse range of activity. In order to investigate how engagement may contribute to learning, and how specific design elements may contribute to engagement, it is first necessary to arrive at a definition of engagement. We can then explore how different kinds of engagement may be categorized and operationalized.

Defining Engagement

The term *engagement* is frequently used in describing aspects of the learning experience. However, a review of the literature on engagement reveals a complex landscape of overlapping definitions and conceptualizations. Engagement has been examined in terms of the classroom (e.g., Axelson & Flick, 2010; Macklem, 2015) and the workplace (e.g., Billett, 2001; Maslach & Leiter, 2008), as well as in the context of games and play (e.g., Boyle, Connolly, Hainey, & Boyle, 2012; O'Brien & Toms, 2008; Prensky, 2005). Engagement is considered to have a positive influence on learning, or even to be essential to learning (e.g., Bouvier, Lavoue, & Sahaba, 2014; Garris & Ahlers, 2002; National Research Council, 2000; Plass, Homer, & Kinzer, 2015), although some caution that it is not simply engagement, but rather specific engaged activities, that support learning (Kinzer, Littlefield, Delclos, & Bransford, 2008; Moreno & Mayer, 2005). Engagement is sometimes described as synonymous with *interest* (Axelson & Flick, 2010), *interactivity* (Salen & Zimmerman, 2004), or *motivation* (Christenson, Reschly, & Wylie, 2012). However, in other discussions, interest, interactivity, and motivation are cited not as *synonyms for* engagement but rather as factors *affected by* engagement (Abdul Jabbar & Felicia, 2015; Ciampa, 2015; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013) or, alternatively, *contributing to* engagement (Aldrich, Rogers, & Scaife, 1998; Garris & Ahlers, 2002). Among other elements named as influencing engagement are individual behaviors or characteristics, including attention (Bouvier et al., 2014), self-regulation (Wolters & Taylor, 2012), and self-efficacy (Klimmt & Hartmann, 2009), as well as system features such as adaptivity (Plass et al., 2015), feedback and challenge (O'Brien & Toms, 2008), or the opportunity for social interactions within the game world (Sellers, 2009). The construct of engagement has been conceptualized on scales that include immersion and/or flow (Brockmyer et al., 2009; Brown & Cairns, 2004; Sharafi, Hedman, & Montgomery, 2006) or that posit engagement as diametrically opposed to disengagement (Fredricks, Blumenfeld, & Paris, 2004; Mosher & MacGowan, 1985), burnout (Bakker & Demerouti, 2008; Maslach & Leiter, 2008), or boredom (Macklem, 2015). In a number of discussions, engagement has been disaggregated into various types or aspects, such as affective, behavioral, cognitive, emotional, motivational, or psychological—each of which has itself been defined in various ways (e.g., Axelson & Flick, 2010; Macklem, 2015; Plass et al., 2015; Whitton & Moseley, 2014).

In attempting to synthesize and reconcile these viewpoints, a portrait of engagement in games emerges. Engagement occurs within the context of a game environment—inside a "Magic Circle of playful learning" (Plass et al., 2015, p. 262), generated by the rules of the game and the participation of players (Salen & Zimmerman, 2004). Engagement originates from the individual in response to a game, sparked by interest, propelled by motivation, and influenced by features of the game itself. Such features may include appealing visuals, interactive opportunities, or a compelling narrative, as well as, more broadly, the social or cultural context in which the game is situated. Finally, and most critically, engagement is defined by activity: An engaged user is taking part in an *active process of meaning-making* (G4LI, n.d.). Such activity may not be readily apparent—for example, cognitive activity cannot be directly observed—but an individual who is *engaged* is actively exerting some type of effort. We therefore propose this simple definition:

> *Engagement in games is the active and focused investment of effort in a game environment.*

This construction describes engagement in terms of *action* on the part of the learner rather than as a property of a game. While clearly emphasizing the importance of individual activity, this definition does not constrain our consideration of the shape of such activity, of the factors that may influence engagement, or of whether such activity will foster learning, all of which we will discuss in some detail. The use of the term *focused* distinguishes engagement from automatic or casual "poking around." *Effort* suggests that the individual is expending energy of some kind (Dewey, 1913). Finally, the term *game environments* describes learning materials with playful elements (Plass, Homer, Mayer, & Kinzer, chapter 1 in this volume).

A number of other definitions or models of engagement, in various contexts, have been proposed. For example, Shernoff (2013), speaking of student engagement in a school environment, suggested that engagement is "the heightened simultaneous experience of concentration, interest, and enjoyment in the task at hand" (p. 12). While this captures the importance of individual factors such as concentration and interest, it also assumes enjoyment, which is not necessarily a component of engagement in the context of games. Imagine, for example, that you are attempting to beat a game level that has already defeated you numerous times. Although still engaged enough to attempt this level once again, you may well have ceased to enjoy it. You may instead be grimly determined to beat the level once and for all. Additionally, though Shernoff's definition implies the idea of activity, referring to the "task at hand," we argue that because activity is central to engagement, it should be explicitly included in any definition.

O'Brien and Toms (2008) conducted a thorough review of user engagement with technology, including web searches, webcasting, and online shopping, as well as gaming. Based on their examination of theoretical bases such as flow, play, and information interaction, they advanced the following definition: "Engagement is a quality of user experiences with technology that is characterized by challenge, aesthetic and sensory appeal, feedback, novelty, interactivity, perceived control and time, awareness, motivation, interest, and affect" (p. 949). Again, this definition includes a number of important factors that may enhance engagement, such as challenge, feedback, and control, but omits the central importance of activity. Additionally, it should be noted that while many of the factors cited in this definition can certainly contribute to engagement, they are not essential for it. For example, there are numerous games that offer little inherent aesthetic or sensory appeal but yet are extremely engaging. Consider, for example, early text-based games such as *Zork* (1981/2017), which rely on the user to imbue unembellished paragraphs of text with imaginative life.

Bouvier, Lavoue, and Sahaba (2014) examined types of engaged behaviors and the terms used in describing engagement across a number of disciplines, offering a helpful discussion of attention, immersion, involvement, presence, and flow. They proposed to define engagement as "the willingness to have emotions, affect, and thoughts directed toward and aroused by the mediated activity in order to achieve a specific objective" (p. 496). Although this definition appropriately takes into account both the individual and the game environment, it focuses on the user's *willingness* rather than the user's *activity*—again, an element we consider critical to any definition of engagement. Renninger and Hidi (2016) make the point that the "will to do something" is distinct from actual involvement in an activity (p. 71).

Despite our differences with these definitions, each of them highlights important elements that should be considered further in discussions of engagement. These elements include individual differences that may drive engagement, such as attention and motivation; user responses, such as enjoyment, emotional investment, or perceived control; and features of game environments, such as feedback and aesthetic appeal, that may influence engagement.

Engagement and Interactivity

It may be useful to consider whether and how engagement is distinct from interactivity, with which it is sometimes conflated (e.g., Salen & Zimmerman, 2004). The two concepts overlap but are not synonymous. Interactivity, like engagement, has been defined in many ways (e.g., Bétrancourt, 2005; Kennedy, 2004; Quiring & Schweiger, 2008), but a defining feature in virtually all these definitions is a reciprocal relationship between two entities. For example, Domagk, Schwartz, and Plass (2010) suggested that interactivity in a computer-based environment is "reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]action of the system and vice versa" (p. 1025). The focus of this definition, like the focus we have proposed in discussing engagement, is on activity. However, interactivity may or may not involve engagement. For example, a player who knows he has lost a battle in *Clash of Clans* might still be idly placing troops or casting spells without a clear goal or focus. This is interactivity but not engagement. Similarly, engagement does not necessarily involve interactivity. A player may be intently focused on a cutscene after completing a challenge in *Uncharted Territory*, but her activity does not influence, in any way, how the cutscene plays out. There is no reciprocal relationship. This is engagement but not interactivity. When we discuss engagement in games, we take into consideration the responses of the game environment, but the spotlight is on the learner. That's where we want it to be, because our focus is on how the individual can make meaning—can *learn*—from a game environment.

Why Engagement Matters

Beyond the intuitive sense that engagement contributes to learning, what do we know about the mechanism of the contribution? This question is not always clearly addressed. For example, one discussion of student engagement states that "learning improves as the quality of cognitive engagement increases and declines as it decreases" (Hannafin & Hooper, 1993, p. 213); the authors add that engagement can foster content knowledge and conceptual understanding. This suggests that engagement supports learning, but it does not reflect on why or how. Other discussions propose that the value of engagement may lie in getting people to do what they otherwise would not want to do, effectively increasing time on task and thus resulting in learning (e.g., Byun & Loh, 2015; Sherry 2004). Still others make a related point, suggesting that engaged game players will be so absorbed in the problems presented in the game environment that they will focus on the satisfaction of challenges surmounted rather than being deterred by the effort involved (Ke, Xie, & Xie, 2015). In other words, engagement may be useful because it distracts learners from the fact that they are learning. Similarly, a recent meta-analysis of studies on engagement in games focused on the potential effects of engagement rather than what it is that makes engagement effective (Girard, Ecalle, & Magnan, 2013). The authors suggest that subjects who are engaged will spend more time on a task, thus making greater progress with a game than they would with nongame materials, and that the higher intrinsic motivation associated with gameplay leads to greater engagement in learning, again with the result that players "learn more" (Girard et al., 2013, p. 216).

While these approaches have merit, we believe that, fundamentally, the significance of engagement turns on one critical proposition: the concept of *active learning*. For some time, educators and educational theorists have focused on the importance of performing specific activities in order to learn. For example, Fröbel, who developed the idea of the modern kindergarten in the late nineteenth century, promoted the idea of critical links between "doing, experiencing, and thinking" (Fröbel, 1894/1904, p. 24). Similarly, both Dewey (1916/1959) and Montessori (1914/1964) drew connections between activity and the construction of knowledge. Some years later, Wittrock (1978), describing the shift from a behaviorist approach to the cognitivist movement in education, would focus more broadly on the idea that learning is not just the product of an instructional environment but rather depends on the "active and constructive role of the learner" (p. 15). Wittrock called this concept *generative learning*, stressing that "comprehension depends directly on what students generate … during instruction" (Wittrock, 1991, p. 169). More recently, Mayer (e.g., 2009, 2011, 2014a), in conceptualizing a model of learning from multimedia materials, described the role of the learner in terms of activity. The learner does not simply receive information or respond to what is presented. Rather, in order for meaningful learning to take place, the learner must actively process incoming information, selecting relevant stimuli, organizing them, and relating them to prior knowledge (Mayer, 2009). The learner is an "active sense maker who … tries to integrate the presented material into a coherent mental representation" (Mayer, 2014a, p.19).

A number of empirical studies support the idea that specific learner activities affect learning outcomes. For example, Glenberg, Gutierrez, Levin, Japuntich, and Kaschak (2004) conducted a series of experiments in which young children were given a set of small toys to manipulate, corresponding to a text that they were asked to read. Manipulating the toys—or even imagining the manipulation of the toys—resulted in significantly higher recall and comprehension scores compared to the scores of a control group that was asked just to read and then reread the material. Another line of research investigated an *enactment effect*: When individuals listened to a list of action phrases (such as "raise your arm") that were read aloud to them, those who were instructed to act out the phrases while listening demonstrated better recall than those who simply listened without performing any actions (Engelkamp & Dehn, 2000; Engelkamp & Zimmer, 1994, 1997). However, this effect was not as strong when participants were imitating the actions of others rather than initiating and performing their own actions (Zimmer & Engelkamp, 1996), suggesting that the degree of conscious investment in activity is a significant factor. Schwartz and Plass (2014) investigated the enactment effect in a gamelike virtual environment in which participants were asked to interact with a series of action phrases read aloud to them on a computer, with accompanying graphics. Each item was randomly presented in one of four conditions, with instructions to listen only, look at a graphic, click to watch an animation, or perform a click-and-drag action. Results indicated that phrases for which participants were asked to click-and-drag were recalled better than items presented under the listen, look, or click conditions. For a summary of learning strategies that were designed to facilitate generative learning, along with their boundary conditions, see Fiorella and Mayer (2016).

Each of these studies demonstrates that activity may play a role in learning. In the context of a game environment, for which we have defined engagement as the *active and focused investment of effort*, we submit that activity is central to the importance of engagement. An engaged user is poised to take part in an *active process of meaning-making* (G4LI, n.d.)—the essence of the learning process. In light of the importance of engagement, it is understandable that researchers have devoted a significant amount of effort to investigating what it looks like, what it does, and how it can be fostered in a game environment.

Current Approaches to Investigating Engagement in Games

As noted earlier, the topic of engagement has been examined from a number of theoretical perspectives. Given this broad range of approaches and definitions, it is not surprising that investigations of engagement in games fluctuate quite widely in terms of the questions addressed and the measures used to capture the construct of engagement. On the one hand, different investigations that aim to examine engagement in games may look at very different constructs or attributes of engagement. On the other hand, studies that do not explicitly address the idea of engagement may in fact be examining aspects of that topic. In this section, we consider a sample of empirical investigations on engagement in games. We then describe an approach to classifying and operationalizing engagement that may provide a systematic framework for organizing current studies as well as scaffolding future research.

In recent years, several meta-analyses dealing with engagement in games have been conducted (e.g., Abdul Jabbar & Felicia, 2015; Boyle et al., 2012; Girard et al., 2013; Vogel et al., 2006; Wouters et al., 2013). A glance at these reviews and a few of the studies analyzed serves to demonstrate the variety of measures that have been used to capture the construct of engagement.

Girard, Ecalle, and Magnan (2013) considered investigations conducted between 2007 and 2011 into whether video games, in particular serious games, have a positive effect on learning and engagement. Only nine studies were ultimately evaluated, two of which examined engagement. One of these two evaluated engagement by using a checklist of classroom engagement behaviors, such as “student works actively on assigned task” and “student infers, problem-solves” (Annetta, Minogue, Holmes, & Cheng, 2009). Researchers compared observations of an experimental group (computer game) and a control group (traditional instruction), finding a significant level of increased engagement for the experimental group. The second study (Wrzesien & Alcañiz Raya, 2010) evaluated engagement in students who were either in a “virtual world” group or a traditional class. The results indicated that students in the virtual world group reported a higher level of engagement than those in the traditional class. To measure engagement, this study relied on three survey questions asking whether participants forgot about the passage of time, were unaware of their surroundings, or forgot worries about everyday life. These items are commonly used to assess immersion or flow (e.g., Brown & Cairns, 2004), which are related to but not necessarily the same as engagement. The studies by Annetta, Minogue, Holmes, and Cheng (2009) and Wrzesien and Raya (2010) both fall into the category of *media comparison* research, which explores the effects of game environments compared to more traditional presentations (Mayer, 2011). Girard et al. (2013), in summarizing these and other studies included in the meta-analysis, concluded that while there is wide agreement on the idea that games that engage and motivate users may benefit learning, further study is needed.

Boyle et al. (2012) cast a somewhat wider net for their meta-analysis, examining studies on engagement in games conducted between 2001 and 2011. Looking specifically at entertainment games rather than learning games, the authors framed their conception of engagement with theories pertaining to the “subjective experience and enjoyment of games," such as flow theory, and "motives for playing games," such as self-determination theory (Boyle et al., 2012, p. 772). Once again, the papers studied applied an array of instruments and methodologies to investigate engagement-related constructs. Studies included in the review used the Positive and Negative Affect Schedule (PANAS) to assess positive or negative moods among participants who received treatments involving a computer game and physical activity (Russell & Newton, 2008); self-reports to measure enjoyment, presence, and flow for participants who were playing against either a human opponent or a computer-controlled opponent (Weibel, Wissmath, Habegger, Steiner, & Groner, 2008); or a combination of surveys, physiological measures, and a word association task to quantify presence and involvement, arousal, and aggression in users exposed to video games with different levels of violence and different levels of graphic and auditory realism (Ivory & Kalyanaraman, 2007). In discussing these various studies, Boyle et al. (2012) took a narrative approach rather than a statistical approach. They categorized the included papers according to main focus (e.g., *subjective feelings of enjoyment while playing games*, *physiological responses to playing games*, or *motives for playing games*) and suggested that it may be useful to think of engagement in terms of a process model with various stages, such as antecedents and outcomes (Boyle et al., 2012, p. 778).

A third meta-analysis, conducted by Wouters, van Nimwegen, van Oostendorp, and van der Spek (2013), focused on the effect of serious games on learning and motivation, with engagement considered under the rubric of motivation. Of particular interest with respect to our consideration of engagement is the fact that these authors specifically addressed the importance of active cognitive processing, and in fact hypothesized that positive effects on learning outcomes for games versus nongame environments might be accentuated when a comparison group received passive rather than active instruction. The meta-analysis concluded that, with respect to learning outcomes, serious games are more effective than conventional methods, with a small effect size ($d = .29$). However, the authors failed to find a significant difference between games and conventional learning environments with respect to motivation. Surprisingly, the hypothesis regarding greater relative benefits for learning when control groups received passive rather than active instruction was not confirmed. The authors noted that this might reflect the fact that most instances of "passive instruction" were short, one-session interventions; when looking at comparison groups that received "active" or "mixed' instruction, the benefit of games increased when the number of sessions increased. Another explanation could be that some "passive" instruction may in fact support cognitive engagement—just because participants were not given an observable task to perform does not mean their attention was not actively engaged. In fact, as we will discuss later, the performance of specific tasks may sometimes interfere with cognitive engagement. Among the studies considered in this meta-analysis, only three specifically addressed engagement: Annetta et al. (2009) and Wrzesien and Raya (2010), both of which we have previously discussed, and Barab, Pettyjohn, Gresalfi, Volk, and Solomou (2012), which assessed engagement in a *game-based* instructional unit versus a *story-based* instructional unit by using a 10-item questionnaire, an assessment of the number of teacher reprimands, and a qualitative analysis of other classroom interactions. Again, these represent diverse approaches to measuring engagement.

The difficulty of pulling together studies as disparate as these to arrive at broad conclusions about the effect of engagement in games indicates that new tactics may be needed. In the following section, we describe an approach to classifying types of engagement that may support finer-grained investigations, and propose ways in which these types may be operationalized.

Types of Engagement

Numerous discussions of engagement have proposed categories such as *cognitive*, *behavioral*, and *affective/emotional* engagement (e.g., Deater-Deckard, Chang, & Evans, 2013; Reschly & Christenson, 2012; Whitton & Moseley, 2014; Wu & Huang, 2007). Often, these classifications are applied to engagement within a school setting (e.g., Fredricks et al., 2004; Reschly & Christenson, 2012). In this context, behavioral engagement is defined as including good conduct and regular attendance in class; cognitive engagement deals with questions such as whether a student is willing to work hard at comprehending curricular content; and emotional engagement includes an individual's reactions to teachers or classmates (Reschly & Christenson, 2012).

These same classifications have been applied to the study of engagement in the context of games, but with significantly different definitions (e.g., Deater-Deckard et al., 2013; Hamari et al., 2016; Plass et al., 2015). For example, because the idea of engagement in the game environment is closely tied to interactivity, Plass, Homer, and Kinzer (2015) turned to INTERACT, the Integrated Model of Multimedia Interactivity (Domagk, Schwartz, & Plass, 2010) to guide their approach to engagement. INTERACT describes interactivity as a dynamic process that involves six interrelated components, including behavioral activities, cognitive/metacognitive activities, and affective factors, as well as the learning environment, individual characteristics of the learner, and the learner's mental model. According to INTERACT, it is the interplay of these components that is important when considering interactivity. Consistent with this model, Plass et al. (2015) proposed that engagement with respect to games can be broken down into *cognitive engagement*, including mental processing and metacognition; *behavioral engagement*, encompassing physical actions such as gestures or movement; *affective engagement*, involving emotional responses within gameplay; and an additional category not specifically referred to in INTERACT, *sociocultural engagement*, including social actions in a cultural context (p. 260). We will consider each of these types in more detail.

Describing and Operationalizing Types of Engagement

What exactly does the engaged learner experience? In the scenarios that follow, we present the four types of engagement we have outlined: behavioral, cognitive, affective, and sociocultural. These types of engagement and their relation to other aspects of game-based learning are described in Plass et al., chapter 1 in this volume. In order to explore the implications of each of these types of engagement in learning from games, and to investigate which kinds of design features may support different kinds of engagement, it is also necessary to arrive at ways to operationalize each category of engagement. In these scenarios we offer a few possible approaches, as well as examples of current research. It is important to note that we draw distinctions among these different types of engagement in order to be better able to explain learning processes. In actual experience, as our examples demonstrate, they are often tightly interconnected.

Behavioral Engagement

A player learning about geometric angles in our game *Noobs v. Leets* must solve problems by selecting rules of angle measurement and indicating to which angles she wants to apply these rules. A correct solution will open a path that can free one of the imprisoned *Noob* characters (figure 3.1). Whether clicking on a rule, clicking on the corresponding angles, or clicking on an escape route for the freed *Noob*, the player's focused performance of specific physical actions constitutes *behavioral engagement*. Behavioral engagement in a game may also include actions and gestures beyond the click of a mouse; for example, swiping a touch screen or performing a full-body movement in a motion-sensitive interface such as Kinect.

In the *Noobs v. Leets* scenario, the actions of selecting a rule, an angle, or a path are behavioral elements. However, they are intended to promote the learner's cognitive engagement in analyzing the problem and finding a solution. The need to make decisions on what to click is designed to lead to active and focused investment in the geometry content of the game.

Game features fostering behavioral engagement The primary way of fostering behavioral engagement in games is through game mechanics and, relatedly, through input devices. Game mechanics describe the "essential play activity players perform again and again" (Salen & Zimmerman, 2004, p. 316), and in well-crafted games for learning, that activity is based on a learning mechanic that is designed to support learning objectives (Plass, Homer, Kinzer et al., 2013). Input devices such as the Microsoft Kinect or Sony PlayStation Move can facilitate activities that go beyond the use of a mouse, keyboard, or controller and allow gestures and embodied actions. For example, researchers modified a reading game for beginning readers, integrating activities in which the 6- and 7-year-old participants acted out specific vocabulary words from the narrative. Results showed that these activities resulted in higher gains in recognition

Figure 3.1
Level in *Noobs v. Leets* (CREATE, 2011).

of high-frequency words and sight words, active decoding, and total reading score, as compared to a group playing the game without these activities (Homer et al., 2014).

Operationalizing behavioral engagement Approaches to measuring behavioral engagement include logging and assessing click counts or mouse coordinates, analyzing user logs, or using trained observers and/or specialized cameras such as the Microsoft Kinect to observe and record body movements and other actions. These data can then be utilized to investigate the experience or the effects of engagement. For example, Bianchi-Berthouze (2013) conducted a study on participants playing *Guitar Hero*, a PlayStation game utilizing a guitar-shaped controller. One group was shown only the basic controller functions, operated by hands alone, while the second group also learned about a tilt function in the neck of the guitar that could be activated. Movements of participants were assessed with data from the PlayStation motion capture system as well as by human observers. After 10 minutes of play, participants completed a questionnaire on engagement. Data were then analyzed to determine whether more movement was correlated with higher scores on the GEQ. Results showed that there were different patterns for the two groups. The researchers conjectured that the availability of different controller functions led to different “levels and types” of engagement in the players: engagement based on “a desire to win” versus engagement based on “the feeling of becoming a guitar player” (Bianchi-Berthouze, 2013, p. 55).

Cognitive Engagement

The online game *Physics Playground* (Shute, Ventura, & Kim, 2013) requires that players guide a ball to a specific target area, marked by a red balloon. To move the ball along, the player must draw lines that can act as levers, wedges, or inclined planes, mimicking real-world physics, and set specific parameters of the environment, as exemplified in figure 3.2.

In order to achieve the goals of the game, players need to experiment with the available tools and observe the results of the actions they take. This kind of active thinking represents cognitive engagement, as players process information, plan their approach, and make decisions. These cognitive activities are described by process theories such as the cognitive theory of multimedia learning and by capacity theories such as cognitive load theory, which Mayer discusses in chapter 4 of this volume. These theories describe the cognitive processes involved in learning as *selecting* (attending to relevant material), *organizing* (mentally arranging it into a coherent structure), and *integrating* (relating it to relevant prior knowledge). They also distinguish among *essential processing*, which involves representing the material in the learner’s working memory; *generative processing*, which involves meaning-making; and *extraneous processing*, which involves processing that does not support the learning goals of the game (Mayer, 2014a). Research on the use of games for second-language acquisition has shown, for example, that a game mechanic not aligned with the desired learning outcome can increase

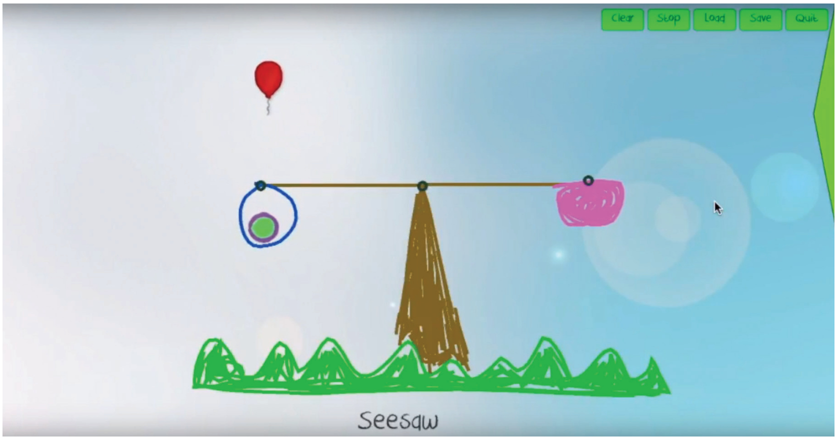

Figure 3.2
Physics Playground (Shute, Ventura, & Kim, 2013).

levels of perceived cognitive load, and decrease vocabulary acquisition (deHaan, Reed, & Kuwanda, 2010).

Coming back to our example of *Physics Playground*, there are other types of engagement at work as well. For example, a player's decisions on whether and how to modify his strategies may represent metacognitive engagement. Engagement in this scenario will also include some behavioral elements (for example, drawing lines) and evoke some affective responses. If the game is played with others, there are also sociocultural mechanisms to consider.

Game features fostering cognitive engagement A key promise of games is that the other forms of engagement discussed in this chapter, namely behavioral, affective, and sociocultural engagement, can all be leveraged to lead to cognitive engagement. For example, a game mechanic in a learning game such as *Physics Playground* may initially evoke some form of behavioral engagement. If the learning mechanic instantiated by this game mechanic was well designed, based on sound theory and empirically validated approaches to learning, then this behavioral engagement can lead to cognitive engagement with the tasks to be solved. For example, researchers compared two different game mechanics for the geometry game *Noobs v. Leets* (CREATE, 2011). Results indicated that the mechanic in which players had to solve missing angles by providing the value for the angle (e.g., 55 degrees), although situationally more interesting, did not result in the same level of learning as a mechanic that required students to specify which angle was given, which angle was missing, and which rule they applied to solve the problem (e.g., complementary angle rule) (Plass, Homer, et al., 2012).

Similarly, incentive systems designed to foster emotional engagement (often combined with behavioral engagement) can foster cognitive engagement. However, extrinsic rewards (e.g., points, stars, stickers) are less likely to result in cognitive engagement than intrinsic rewards that are tied to the specific game mechanic, such as power-ups that unlock new learning-related tools or new areas within the game (Ryan & Rigby, chapter 6 in this volume).

Following research on multimedia learning, different game elements can be used to prime *selection, organization*, and *integration* of information, all of which are key to cognitive processing (Mayer, 2014b). Supporting these processes can lead to cognitive engagement. For example, a study by Plass, Homer, Schwartz et al. (2013) investigated the use of visual cues in a gamelike simulation to signal important elements and prompt integration of multiple representations of information. Results indicated that this support for selecting and integrating critical information led to improved transfer scores in content posttests.

Operationalizing cognitive engagement Cognitive engagement might be assessed using the number of problems attempted, the number of solutions generated, the amount of time spent on a task, or the individual's choice to remain in the game environment for an extended period. Inspection of log files can reveal deliberate patterns of behavior, which might reflect a player's learning or thinking about how to proceed (Shute & Sun, chapter 20 in this volume). For example, user logs can be used to identify students gaming the system (Baker et al., 2006) or to make inferences about learners' metacognition, motivation, and self-regulated learning (Winne & Baker, 2013). Surveys asking users to report on their mental effort, either during a task or after its completion, can also be used (Sharek & Wiebe, 2014). The analysis of gaze patterns (eye tracking) allows specific insights into the parts of the game or simulation to which a user paid attention, thereby revealing cognitive engagement with different aspects of the game (e.g., O'Keefe et al., 2014). Neuroscience measures such as EEGs have been used to monitor brain activity as an indication of cognitive engagement in game-based and other forms of learning (Anderson et al., 2011). One study examining students' use of a computer simulation about kinetic molecular theory noted that higher learning outcomes were correlated with lower levels of classroom conversation (Plass, Milne, et al., 2012). The authors suggested that what appeared to be an absence of activity actually indicated the presence of cognitive engagement—students enjoying "space to think" (Plass, Milne, et al., 2012, p. 410).

Affective Engagement

An individual playing our game *All You Can E.T.* (CREATE, 2016) is responsible for serving food and drinks to a horde of orange and green aliens (figure 3.3). The rules about which aliens prefer which kinds of food and drink change frequently, since the game is designed to train cognitive skills, specifically executive functions (EFs) (Homer, Plass, Raffaele, Ober, & Ali, 2018; Parong et al., 2017).

The appearance of the alien characters has been designed to evoke an emotional response in players, based on previous research identifying which visual designs for the aliens induced the highest emotional arousal in players (Plass et al., in press). Research further showed that this high arousal, also referred to as Hot EF, resulted in higher gains in cognitive skills compared to a game with characters inducing lower arousal levels (Homer, Plass, Rose et al., 2019; Ober et al., 2017). Learners' emotional response to game elements, in this case to the game characters, is an example of affective engagement. Game environments that draw on attitudes and beliefs may also evoke affective engagement.

In this scenario, fostering affective engagement serves two purposes. First, since the cognitive demands of these games are high and players may not want to invest such intense levels of mental effort over longer periods, the player's emotional engagement with the aliens aims to lead to longer play times. In addition, emotional engagement may increase the training effect of the game through the involvement of the limbic system (Plass & Kaplan, 2016). Enhancing cognitive engagement is not the only function affective engagement might play in a game, however. Some games may have affective rather than cognitive goals. For example, *PeaceMaker* (Burak, 2004) and *Darfur Is Dying*

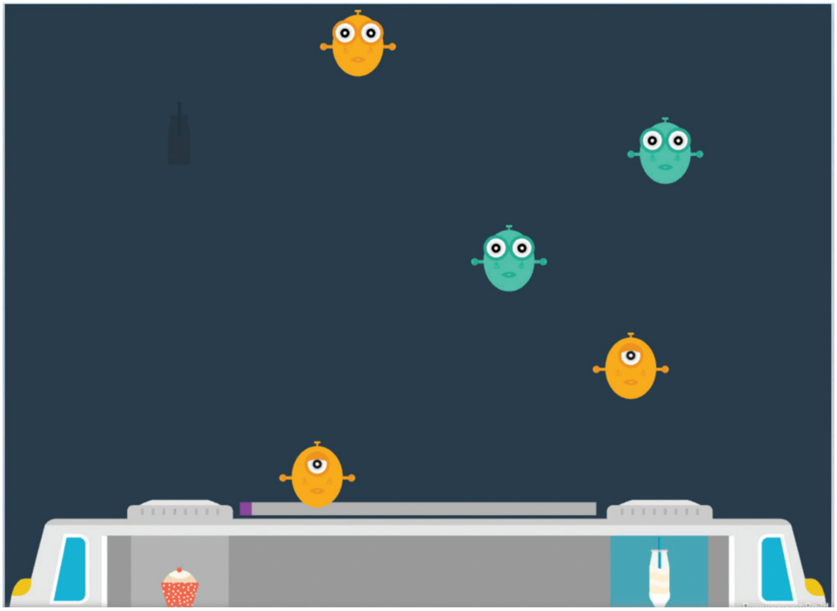

Figure 3.3
Game characters in *All You Can E.T.* (CREATE, 2016).

(Ruis, 2006) aim to promote empathy and change players' attitudes. Other games may use affective engagement to facilitate social engagement.

Game features fostering affective engagement Many of the design features that are specific to games can be used to foster affective engagement. These include the aesthetic design, the incentive system, game characters, narrative, sound and musical score, and other elements that have been summarized in the context of *emotional design*. Emotional design is the deliberate use of game design elements to induce specific emotions, with the goal of enhancing learning (Plass & Kaplan, 2016; see also Loderer, Pekrun, & Plass, chapter 5 in this volume). However, features such as feedback or guidance, which may have been designed to foster other types of engagement, may also influence emotions. For example, in games involving intelligent tutoring systems, feedback generated by the games sometimes led to feelings of frustration and confusion, which in turn supported cognitive engagement and learning (D'Mello & Graesser, 2012).

Operationalizing affective engagement Approaches for investigating affective engagement primarily include measures of emotion. These may utilize self-reports of emotions (Um, Plass, Hayward, & Homer, 2012), the analysis of user logs (Pardos, Baker, San Pedro, Gowda, & Gowda, 2014), gaze pattern analysis (Jaques, Conati, Harley, & Azevedo, 2014), or physiological markers such as skin conductance or respiration patterns (Conati, Chabbal, & Maclaren, 2003; Woolf et al., 2009). Recent technical advances have made it possible to assess affective states using techniques such as EEG or fMRI (e.g., Mathiak & Weber, 2006; McMahan, Parberry, & Parsons, 2015; Salminen & Ravaja, 2008). Affective engagement may also be operationalized through surveys designed to assess changes in attitudes or beliefs (Alhabash & Wise, 2012).

Sociocultural Engagement

In the game *Civilization III*, learners collaborate to set their own goals, decide on strategies for how to achieve these goals, and assign different roles to players in pursuit of the goals (Squire, 2008). Insights on the processes and outcomes of these kinds of meaning-making activities are shared with others in forums, via fan fiction, and as walkthroughs. This is sociocultural engagement, which highlights social interactions as being essential to learning (Steinkuehler & Tsaasan, chapter 7 in this volume). The human need to feel connected to others, referred to in self-determination theory as *relatedness*, has been proposed as one factor in people's motivation to play games (Boyle et al., 2012).

Other games pursue goals related to culture. For example, *Never Alone* (2015) is an atmospheric puzzle platform game conceptualized by members of the Cook Inlet Tribal Council in Anchorage, Alaska, and developed with the oversight of this group (Byrd, 2014; see figure 3.4). The game narrative is based on a traditional Iñupiaq story. A player may take on the role of a small girl, Nuna, or her friend, an Arctic fox; users can play alone or in a cooperative mode. As Nuna and the fox progress, they face a blizzard and other dangers that they must overcome in order to save their village. In confronting and overcoming these challenges, players come to understand and value not only specific facts about Iñupiaq culture but also a rich cultural perspective.

This represents several aspects of "sociocultural engagement": the use of cultural influences to motivate learning in the game environment, as well as the opportunity to play cooperatively in order to meet game objectives (Steinkuehler & Tsaasan, chapter 7 in this volume). In this case, the game design aims to boost sociocultural engagement in order to support a direct outcome in the learner, that of feeling connected to and respecting Iñupiaq culture. This kind of engagement also comes into play when a game provides social support for learning through group activities or missions (Plass et al., 2015) or utilizes a culturally familiar experience or narrative as a scaffold to structure new understandings.

Game features fostering sociocultural engagement Sociocultural engagement can be fostered with the design of social features in a game and in the emergent culture that games create. Within a game, features may include chat functions and other ways of real-time communication, mechanics that allow multiplayer options and role-playing,

Figure 3.4
Never Alone (2015).

game characters that facilitate collaboration and communication, and incentives that reward these activities. The emergent culture, including affinity groups, fandom, and the like, is shaped by the players themselves but can be supported by providing sites hosting forums or other game-specific social media (Steinkuehler & Tsaasan, chapter 7 in this volume). Apostolellis, Bowman, and Chmiel (2018), looking at groups of children interacting with games in museum environments, identified appropriate levels of guidance as another important factor in supporting social engagement.

Operationalizing sociocultural engagement Approaches to measuring sociocultural engagement span a broad range of research methods, which include surveys, social network analysis, interviews asking learners about their collaborative actions, discourse analysis (Steinkuehler, 2006), and many more (Steinkuehler & Tsaasan, chapter 7 in this volume).

Summary

Clearly, it is not possible to draw hard lines between types of engagement—as noted in our examples, the user may be engaged in a number of ways at one time. Similarly, quantifying engagement is complex; a specific measure such as amount of time spent could reflect more than one type of engagement. However, building a construct of engagement that includes a range of activities reminds us that learning is not exclusively a cognitive process, but also arises from our embodied actions, our emotions and motivation, and how we are situated within a sociocultural context.

Practical and Theoretical Implications

Our discussion of engagement in game-based learning has important theoretical as well as practical implications. On the theoretical side, conceptualizing the construct of engagement as a diverse range of experiences—behavioral, cognitive, affective, and sociocultural—enables a more nuanced discourse about engagement and allows us to reassess current research on engagement, which at present may aggregate results that are not actually comparable. For example, as previously noted, a measure of engagement assessing whether a student forgot about the passage of time (e.g., Wrzesien & Raya, 2010) is not necessarily addressing the same construct as a measure of engagement that records whether a student was working actively on a particular task (e.g., Annetta et al., 2009). An expanded understanding of engagement also affords the opportunity to include investigations that were not primarily framed as engagement studies but do in fact look at these factors. For example, Böckler, Hömke, and Sebanz (2014) conducted a study to investigate social exclusion in the context of a digital "looking game" (p. 141) in which human participants either received or did not receive direct eye gazes from their virtual game partners. Responses of the participants were recorded using eye-tracking technology. Following the experiment, participants completed surveys including questions on whether they felt included during the game. Though not framed as such, this study examines what we would classify as sociocultural engagement. As a result of such reassessment of the existing literature, a conceptually clearer model of engagement can be described that will support further theoretical insights. Within the categories of behavioral, cognitive, affective, and sociocultural engagement, a structure for investigation can be established, such as that proposed by Ivory and Kalyanamaran (2007) in discussing involvement. They suggest that "conceptualization[s] of involvement" can focus on a user's experience, taking into consideration *antecedents* of user experience, such as motivation or prior knowledge, as well as *consequences* of different levels of involvement, such as strategies used or learning outcomes (see also Andrews, Durvasula, & Akhter, 1990; Boyle et al., 2012). Similarly, O'Brien and Toms (2008) propose a process model of engagement, starting at the *point of engagement* and progressing through the *period of engagement*, *disengagement*, and potential *reengagement* (p. 945).

On the practical side, a clearer conceptual separation of the different types of engagement in learning with games provides much-needed guidance for practitioners, game designers, and games researchers. Any theory of change describing the strategies employed in a game for learning can refer to specific game features designed to elicit a specific type of engagement, and how this type of engagement will contribute to the intended learning outcomes, both proximal and distal. These claims can then be verified by a *value-added* approach to research on games (Mayer, 2011, 2014b) focusing on specific design features that may affect instructional impact.

Directions for Future Investigation

Our review of the literature has revealed many important areas remaining for investigation related to engagement, and we outline the most important ones in this section.

Investigate antecedents of engagement. Although research has begun to investigate design factors that lead to the various types of engagement, the antecedents of engagement are not fully understood. To what extent can motivation, prior knowledge, or other learner variables lead to engagement? What variables mediate or moderate these relationships? These questions apply to all learning environments but take on special meaning when we consider engagement in games for learning.

Identify and validate specific game design features that foster specific types of engagement. Research identifying design features that elicit cognitive, affective, behavioral, or sociocultural engagement exists, but a systematic investigation of these features is needed to better guide the design of games for learning. As our review of the literature has shown, the lack of conceptual clarity has hampered this kind of research.

Refine measures of engagement in games that are valid, reliable, and can operate in real time. The measures for engagement employed in the studies we reviewed show that there is little agreement among researchers regarding how engagement can be operationalized and measured: One comprehensive review of studies on engagement in human-computer interaction enumerates 25 different approaches to gathering data, ranging from administering questionnaires to monitoring various physiological markers (Doherty & Doherty, 2019). Because games provide many opportunities for the collection of process data, they may be particularly well suited for development of measures based on analysis of such information, perhaps using physiological measures for triangulation. Researchers also emphasize the importance of study design; for example, the meta-analysis by Wouters et al. (2013) notes differences between findings when looking at short, one-session implementations rather than multiple sessions. Adams, Mayer, MacNamara, Koenig, and Wainess (2012) make a similar point regarding duration of play when discussing the limitations of their findings on the benefits of narrative-themed games.

Patterns of engagement and their effect on learning. We have argued that the learner experience in games may include multiple types of engagement and that more research is required to investigate patterns and outcomes of engagement—to what extent one type of engagement may lead to another, and how types of engagement are connected to types of learning outcomes. For example, we have discussed various kinds of engagement in our math game *Noobs v. Leets* (CREATE, 2011). Like types of engagement, desired learning outcomes for that game also vary. We may hope to see the ability to solve problems within the game or to transfer problem-solving skills to content outside the game (cognitive outcomes); improved attitudes toward math (an affective outcome); or successful collaboration with other students (a sociocultural outcome). For novice learners, behavioral engagement with the beginning levels of the game might simply offer the opportunity to practice moving and clicking the mouse (a behavioral outcome).

Conditions of engagement. Finally, further research should investigate under what conditions engagement is beneficial to learning. For example, some elements designed to foster engagement may require learners to process excessive nonessential information, leading to cognitive overload and adversely affecting desired learning outcomes (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012).

Conclusion

In this chapter, we examined the definition of engagement in games and the importance of engagement in learning. We proposed a new definition of engagement in games as *the active and focused investment of effort in a game environment*, emphasizing the importance of individual activity while allowing the consideration of a broad range of other factors. In light of the difficulty of generalizing about engagement, we proposed an approach to classifying and operationalizing different types of engagement: behavioral, cognitive, affective, and sociocultural. Investigating engagement in this way may permit a more nuanced understanding of how engagement can be fostered in a game environment; which game design elements can be used to elicit each form of engagement; and how these can be operationalized and measured. Finally, we outlined a research agenda that would provide much-needed empirical evidence on *how to generate engagement*, identifying design factors and underlying mechanisms that take into account learner differences; *different types of engagement*, identifying patterns and processes of engagement; and *outcomes of engagement*, identifying how specific types of engagement relate to specific learning outcomes.

Because games are not chemical compounds, it is unlikely that we can arrive at precise formulas that will generate ideal games—it is not a question of combining a specific number of units of scaffolding, visual realism, or deep narrative. Rather, empirical studies on engagement have the potential to inform our understanding of an array of factors to consider in the design of games for learning; which tools, strategies, or design features we can use to aid the job at hand. Looking at engagement through behavioral, cognitive, affective, and sociocultural lenses allows us to perceive a fuller spectrum: what are the many ways in which a learner may actively invest effort in a game environment? This encourages a more complete representation of the process of learning, and a better understanding of how we can most effectively support learners through and with games.

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II Theoretical Foundations of Game-Based Learning

4 Cognitive Foundations of Game-Based Learning

Richard E. Mayer

Introduction

Game-based learning occurs when playing a game causes a change in the player's academic knowledge (including cognitive skill). This chapter examines how to design computer games and simulations that foster academic learning in players by taking an approach that is grounded in a cognitive theory of how people learn and based on research evidence from scientifically sound experiments. According to the cognitive theory of game-based learning, game playing may foster generative processing (i.e., cognitive processing aimed at making sense of the material and attributed to the player's motivation), but it may also create extraneous processing caused by the distracting glitzy features of the game (i.e., cognitive processing that does not support the instructional objective of the game). Given the limited capacity of players' information processing systems, when players devote too much of their available cognitive capacity to extraneous processing, they may not have sufficient remaining capacity to engage in essential processing (i.e., representing to-be-learned material in their working memory) and generative processing. Designing effective educational games requires a balance of instructional features that minimize extraneous processing and manage essential processing and game features that promote generative processing. Three research genres of experimental research on game-based learning are value-added experiments, cognitive consequences experiments, and media comparison experiments. Value-added research identifies five promising features that improve learning from computer games: personalization, modality, pretraining, coaching, and self-explanation. Cognitive consequences research shows that playing first-person shooter games such as *Unreal Tournament* improves perceptual attention skill and playing the spatial puzzle game *Tetris* improves 2D mental rotation skill. Media comparison research shows that learning from a game can be more effective than (or as effective as) learning from conventional media, particularly with science content. Future directions include conducting replication studies, identifying boundary conditions, broadening the context of study, focusing on learning outcomes, and focusing on learning processes.

What Are the Cognitive Foundations of Game-Based Learning (and Some Examples)?

An Example of Game-Based Learning

How can we design computer games and simulations so they foster academic learning in players? This is the question that motivates this chapter on the cognitive foundations of game-based learning. Consider a computer game in which you travel to a new planet that has a specific climate, such as frequent rain and winds. You are asked to construct a plant that will survive on the planet by choosing one of eight types of roots, one of eight types of stems, and one of eight types of leaves. Then, you get to see how well your plant survives, while Herman the Bug explains how the plant features affect its growth in the planet's climate. The goal of this game is to help players learn some basic principles of environmental science concerning how structural features of plants affect plant growth in various environmental conditions. A screenshot from this game, called *Design-a-Plant*, is shown in figure 4.1 (Moreno, Mayer, Spires, & Lester, 2001).

Three Components in the Cognitive Approach to Game-Based Learning

In this chapter, I take a cognitive approach to game design by focusing on learning processes and outcomes involved in playing a computer game such as *Design-a-Plant*. Let's

Figure 4.1
Screenshot from *Design-a-Plant*.

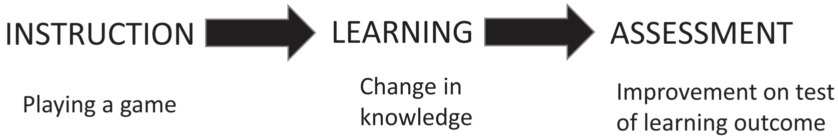


Figure 4.2
Major components in the cognitive approach to game-based learning.

begin by clarifying three major components in the cognitive approach to game-based learning: learning, instruction, and assessment. These components are summarized in figure 4.2.

Learning is defined as a change in someone's knowledge due to experience (Mayer, 2011). This definition has three parts: (1) learning involves a change in the learner, (2) what is changed is the learner's knowledge, and (3) the change is caused by the learner's experience. In the case of game-based learning, the change is caused by a specific type of experience, namely, playing a computer game. Thus, *game-based learning* is defined as a change in someone's knowledge as a result of game playing. In the case of the *Design-a-Plant* game, we seek a change in the learner's knowledge about plant growth, including a mental model of how water and sunlight are involved.

Instruction is defined as a manipulation of the environment that is intended to cause learning (Mayer, 2011). In the case of game-based learning, asking someone to play a game can be seen as a manipulation of the learner's environment, which is intended to prime experiences that lead to a change in the learner's knowledge. Instruction in games can vary from providing almost no guidance at all to providing detailed guidance and feedback, but as long as games are intended to help the player learn academic content, we can consider them a form of instruction. Accordingly, academic games should have clear *learning objectives*—descriptions of the knowledge to be learned from playing the game and how that change in knowledge will be assessed. For example, in the *Design-a-Plant* game, one learning objective may be to be able to describe the best environmental conditions for a specific plant.

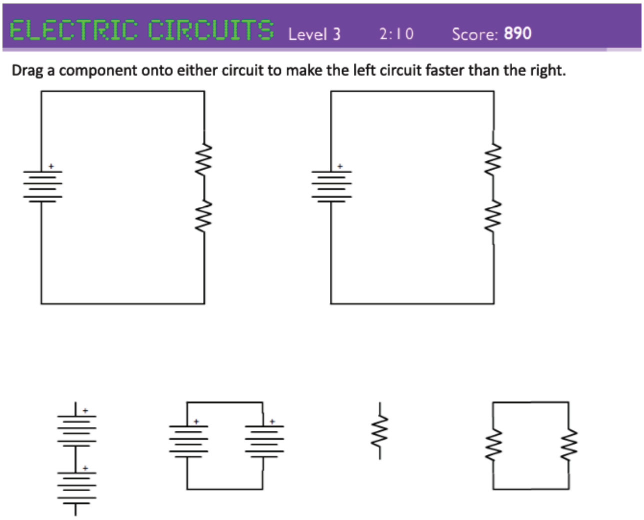
Assessment is defined as determining what the learner knows (Mayer, 2011; Pellegrino, Chudowsky, & Glaser, 2001). In order to determine whether game-based learning has occurred, we need a way to assess the learner's knowledge. Sometimes the assessments can be embedded in the game, in the form of *stealth assessment* (Shute & Ventura, 2013), and sometimes the assessments can be external to the game, in the form of a formal posttest. Two common types of tests are *retention tests*, which measure what the learner can remember, and transfer tests, which measure how well the learner can apply what was learned to new situations. For example, in the *Design-a-Plant* game, a transfer test item that assesses the instructional objective could be to show the learner a plant with specific roots, stem, and leaves and ask the learner to describe the environment best suited for its growth, such as knowing that a plant with long, shallow roots would thrive in a dry climate.

As you can see from figure 4.2, knowledge is at the heart of the cognitive foundations of game-based learning. The common element running through game-based learning, game-based instruction, and game-based assessment is a focus on knowledge, or what can be called learning outcomes. Learning involves a change in knowledge, instruction fosters a change in knowledge, and assessment determines the change in knowledge. In light of the central role of knowledge—or learning outcomes—in game-based learning, this chapter takes a cognitive approach by examining the cognitive foundations of game-based learning.

Types of Knowledge in Game-Based Learning

As another example of a computer game for learning, consider the *Circuit Game*, as shown in figure 4.3 (Johnson & Mayer, 2010; Mayer & Johnson, 2010). This game has 10 increasingly challenging levels, in which players must solve electrical circuit problems such as dragging and dropping batteries and/or resistors to create current flow in a new circuit that is equivalent to another circuit that is shown on the screen. The goal of the *Circuit Game* is to help students learn how electrical circuits work based on Ohm's law.

Table 4.1 summarizes five kinds of knowledge that can be targeted in educational computer games such as the *Circuit Game* (Anderson et al., 2001; Mayer, 2011). First,



Drag a component onto either circuit to make the left circuit faster than the right.

Figure 4.3
Screenshot from the *Circuit Game*.

Table 4.1
Five types of knowledge

Type	Description	Example
Facts	Basic statements about the world	Resistance is measured in ohms.
Concepts	Categories, schemas, principles, model	Current decreases in a circuit when resistance increases.
Procedures	Step-by-step processes	Solve for I if $V = 20$ and $R = 10$ in the formula $I = V/R$.
Strategies	General methods	When solving an equation involving Ohm's law, draw a diagram.
Beliefs	Thoughts about learning	"I am good in science."

players can develop *factual knowledge*, such as knowing that resistance is measured in ohms. Second, players can develop *conceptual knowledge*, such as knowing that resistance is like a constriction in a water pipe. Third, players can develop *procedural knowledge*, such as knowing how to use the formula for Ohm's law to compute the value of I if $V = 20$ and $R = 10$. Fourth, players can develop *strategic knowledge*, such as restating a problem in your own words or judging how confident you are in your solution. Fifth, players can develop *beliefs*, such as the idea that "I am good in science." Computer games for learning can seek to build a combination of types of knowledge.

A Cognitive Theory of Game-Based Learning

How do players learn academic content from playing a computer game? Figure 4.4 presents a cognitive theory of game-based learning adapted from the cognitive theory of multimedia learning (Mayer, 2009) and cognitive load theory, from which it is derived (Sweller, Ayres, & Kalyuga, 2011). The theory draws on three fundamental principles of cognitive science (Mayer, 2009, 2011):

Dual-channels principle People have separate (but interacting) channels for processing visual and verbal information.

Limited capacity principle People can process only a small amount of material in each channel at any one time.

Active processing People learn by paying attention to relevant incoming information, mentally organizing it into a coherent structure, and integrating it with relevant prior knowledge activated from long-term memory.

The dual-channels principle is represented in figure 4.4 as two rows, with the verbal channel on the top and the visual channel on the bottom. Limited capacity is represented as the box labeled WORKING MEMORY. Active processing is represented by the arrows for selecting, organizing, and integrating.

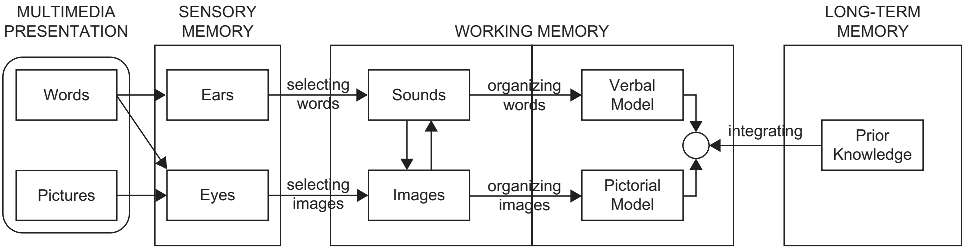


Figure 4.4
Cognitive theory of game-based learning.

Playing a game involves processing visual and verbal information. As can be seen in figure 4.4, during game playing, spoken words enter through the player's ears and are held briefly in sensory memory, where they fade within a fraction of a second. If the player pays attention to the fleeting words, they are transferred to working memory (indicated by the *selecting words* arrow), where the player may seek to organize them into a coherent representation called *Verbal Model* in the figure (represented by the *organizing words* arrow). In parallel, during game play, images and printed words enter through the player's eyes and are held briefly in sensory memory, where they fade within a fraction of a second. If the player pays attention to the fleeting images, they are transferred to working memory (indicated by the *selecting images* arrow), where the player may seek to organize them into a coherent representation called *Pictorial Model* in the figure (indicated by the *organizing images* arrow). Also, images of printed words are converted to sounds for processing in the verbal channel. Finally, the *Verbal Model* and *Pictorial Model* are integrated with each other and with incoming prior knowledge from long-term memory (indicated by the *integrating* arrow). The learning outcome created in working memory is then stored in long-term memory.

During game playing, the player has only a limited amount of processing capacity for each channel, which must be allocated among three possible uses:

Extraneous processing is cognitive processing that does not support the instructional goal, such as when the learner is distracted by extraneous material in the game. An important instructional design goal is to minimize extraneous processing, such as by eliminating extraneous material from the screen or highlighting important material.

Essential processing is cognitive processing needed to mentally represent the visual and verbal material in working memory, represented mainly by the *selecting* arrows in the figure, and some low-level organizing. An important instructional design goal is to manage essential processing, such as by providing pretraining or presenting words in spoken form rather than printed form.

Generative processing is cognitive processing aimed at making sense of the material, represented by the *organizing* and *integrating* arrows in the figure. An important instructional goal is to foster generative processing, which can be accomplished through using conversational language style or having on-screen agents that display humanlike gestures.

It is important to note that if players use most of their cognitive capacity resources for extraneous processing, they may not have enough cognitive capacity left for essential and generative processing, which are needed for meaningful learning.

Games are intended to foster generative processing by virtue of their motivational properties, but they may also create extraneous processing and reduce essential processing because of many distracting details on the screen. In contrast, conventional instructional media that are used simply to present information or to drill cognitive skills are sometimes criticized for their failure to foster generative processing and lauded when they employ multimedia design principles that reduce extraneous processing and manage essential processing. The balancing act required in the design of educational games is to include enough game features to maintain the motivation for generative processing while including enough instructional features so the learner is not too distracted with extraneous processing and can instead find the essential content.

It is also important to note that if learners are not motivated to learn, they may not engage sufficiently with the material and hence may not produce robust learning outcomes. Computer games have the potential to promote learner motivation, reflected in learners engaging with the material, which can lead to generative processing. At the same time, computer games may create extraneous processing, by causing the learner to engage in cognitive processing that does not serve the instructional goal even though it does help the learner maintain a high level of motivation.

Are computer games an efficient way to learn? Some educators may answer "no" because there are forms of instruction that are more direct, such as presenting the material in a tutorial. However, if students are not motivated to engage with the lesson, then direct methods will not result in the desired learning outcomes. In situations where students can choose how long they will persist and how strongly they will engage, computer games can be a preferred venue. For example, most students would not choose to watch a tedious slideshow presentation during their free time, but they might choose to play a computer game that conveys the same academic content, albeit perhaps not as efficiently as in a slideshow. In short, in some situations, it is better to have students choose to engage with a less efficient lesson (e.g., a computer game) than not choose to engage with a more efficient lesson (e.g., slideshow tutorial).

What Do We Know about the Cognitive Foundations of Game-Based Learning?

In reviewing experiments on game-based learning, I (Mayer, 2014a, 2016) identified three genres of game-based research: (1) *value-added* research, (2) *cognitive consequences* research, and (3) *media comparison* research. Table 4.2 summarizes the characteristics of each of these three genres of game research.

In value-added experiments, researchers compare the learning outcome of a group that plays a base version of a game to the learning outcome of a group that plays the same game with one feature added. For example, consider an experiment in which the control group plays the *Design-a-Plant* game with the narrator speaking in formal style, whereas the experimental group plays the same game except that the narrator speaks in conversational style, and both groups take a posttest on the material. This design allows the researcher to determine whether changing from formal to conversational style causes an improvement in learning outcome.

In cognitive consequences experiments, researchers compare the learning outcome of an experimental group that plays a game (e.g., playing an off-the-shelf game produced by a commercial publisher) to the learning outcome of a control group that engages in a control activity (e.g., playing a completely different game or not playing any game). For example, consider an experiment in which the experimental group plays a game that appears to target spatial skill (such as *Tetris*), whereas the control group plays a game that does not appear to target spatial skill (such as a word-search game), and both groups take posttests on spatial cognition tasks (such as mental rotation). This design allows the researcher to determine whether playing the experimental game causes improvements in a targeted cognitive skill.

In media comparison experiments, researchers compare the learning outcome of an experimental group that learns material by playing a game to the learning outcome of a control group that learns the same material through conventional media (such

Table 4.2
Three genres of experimental research on game-based learning

Game research genre	Research question	Research design
Value added	Which features of a game promote learning?	Compare learning outcome for base version of game vs. base version with one feature added.
Cognitive consequences	Does playing an off-the-shelf game promote learning?	Compare learning outcome from playing an off-the-shelf game vs. engaging in a control activity.
Media comparison	Do games promote learning better than conventional instructional media?	Compare learning outcome from playing a game vs. conventional instruction on the same material.

Table 4.3
Three defining characteristics of experimental research on game-based learning

Characteristic	Definition	Example of violation
Experimental control	The experimental and control groups are equivalent on everything except the independent variable.	The game group consists of all girls, and the control group consists of all boys.
Random assignment	The participants are put into the experimental or control group based on chance.	Participants choose whether they want to play a game or engage in a control activity.
Appropriate measures	The dependent measures include tests of learning outcome.	The test solely involves asking participants to rate how much they liked the activity.

as video, narrated slideshow, or illustrated text). For example, consider an experiment in which one group learns about plant growth by playing the *Design-a-Plant* game, whereas another group learns the same material from an online, narrated animation, and then both groups take a posttest on the material. This design allows the researcher to determine whether the game caused more, less, or equivalent learning as compared to conventional instruction.

Although observational research can provide useful information about game-based learning, I focus on experimental research in this chapter because experiments are the most appropriate methodology for testing causal claims about the effects playing computer games have on learning (Phye, Robinson, & Levin, 2005; Shavelson & Towne, 2002). Table 4.3 lists the three defining characteristics of experimental research that form the basis for selecting studies to include in a review of experimental research on game-based learning: *experimental control*, *random assignment*, and *appropriate measures*.

Experimental control refers to the requirement that the experimental and control groups be equivalent on all relevant variables except for the one that is being varied (i.e., the independent variable), based on the classic call to vary one thing at a time. For example, experimental control is violated if the participants in the experimental and control groups have different basic characteristics before the start of the experiment (such as differences in age, proportion of males and females, or level of prior knowledge).

Random assignment refers to the requirement that the participants in the experiment be placed into the treatment or control group by chance. For example, random assignment is violated if participants are allowed to choose the group they would like to be in.

Appropriate measures refers to the requirement that the test involves an assessment of learning outcome; that is, an assessment of the knowledge or skill intended to be taught in the game. For example, the requirement of appropriate measures is violated

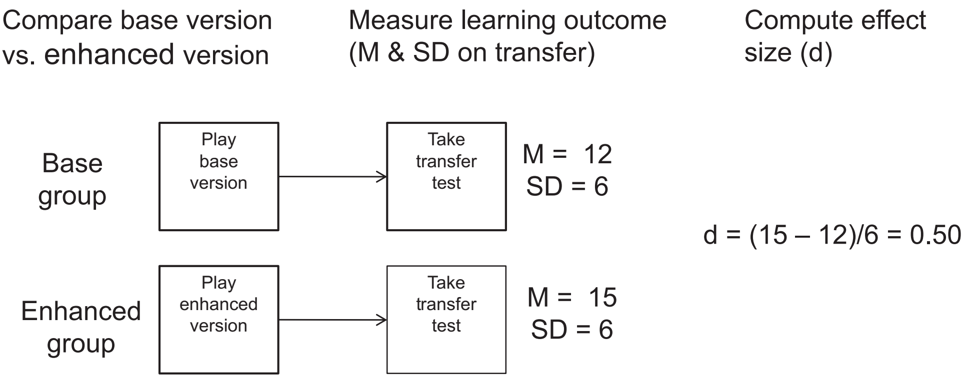


Figure 4.5
A value-added experiment.

when the test asks participants to rate their feelings instead of determining how participants can perform using the knowledge or skills targeted in the game.

The next three subsections summarize research in each of the three research genres that meet these requirements of scientifically sound experimental research on games for learning. Given length limitations, I provide examples of research conducted in or in conjunction with our lab.

Value-Added Research on Game-Based Learning

As depicted in figure 4.5 (adapted from Mayer, 2014a), in value-added experiments, participants play a base version of a game (control group) or an enhanced version of the same game (experimental group) and then take a test on the material, preferably a transfer test that requires them to apply what they have learned.

This design is beginning to generate preliminary findings concerning which game features improve learning and which game features do not. Table 4.4 lists five promising game features and two unpromising features based on a review by Mayer (2014a) and provides a brief description of each principle, the median effect size based on Cohen's *d*, and the number of positive tests (out of the total number of experiments).

Modality principle of game design Consider the *Design-a-Plant* game as depicted in figure 4.1. In this game, the players are asked to choose the roots, stem, and leaves of a plant that is suited to live on a planet they are visiting, which has certain environmental conditions, such as being rainy and windy. A local inhabitant, Herman-the-Bug, then observes what happens to the plant and explains how plants grow. In the base version of the game, Herman's words are printed as on-screen text, whereas in the enhanced version of the game, Herman's words are presented as spoken text. Across nine experiments involving a variety of contexts (such as with or without Herman's

Table 4.4
Which game features improve learning?

Feature	Description	Effect size	Number
Promising features			
Modality	Present words in spoken form.	1.41	9 of 9
Personalization	Use conversational style.	1.54	8 of 8
Pretraining	Provide pregame experiences.	0.77	7 of 7
Coaching	Provide advice or explanations.	0.68	6 of 7
Self-explanation	Provide prompts to explain.	0.81	5 of 6
Unpromising features			
Immersion	Use virtual reality.	–0.14	2 of 6
Redundancy	Provide printed and spoken words.	–0.23	0 of 2

image on the screen, or with delivery by desktop computer or virtual reality), in every experiment, students learned better with spoken text than with printed text, yielding a median effect size of 1.41 (Moreno & Mayer, 2002a; Moreno et al., 2001). This pattern supports the *modality principle of game design*: people learn better from games containing spoken words than from those with printed on-screen words. Caution in interpreting the findings is warranted, however, given that all the support for the modality principle listed in the top line of table 4.4 comes from the same game tested in the same lab.

Personalization principle of game design Once again, consider the *Design-a-Plant* game depicted in figure 4.1. In the base version, Herman-the-Bug communicates using formal style (e.g., “This program is about what type of plant survives on different planets”), and in the enhanced version, he communicates in conversational style using first- and second-person pronouns (e.g., “You are about to begin a journey, where you will be visiting different planets”). Across five experiments comparing formal style to conversational style in the *Design-a-Plant* game (Moreno & Mayer, 2000, 2004), students learned more in the version with conversational style in every experiment, yielding a median effect size of 1.58. The second line in table 4.4 includes these five experiments as well as three others involving math and engineering games, all favoring conversational style and yielding a median effect size of 1.54. This pattern supports the *personalization principle of game design*: people learn better from games containing words in conversational style rather than in formal style.

Pretraining principle of game design Consider the *Circuit Game* depicted in figure 4.3. In the base version, the player goes through the 10 levels of the game, solving circuit problems along the way. In the enhanced version, the player goes through exactly the same game, but before the game, the player receives a brief tutorial on the principles of electrical circuits and the meaning of the circuit symbols. In an experiment by Fiorella and Mayer (2012), students who received pretraining scored much higher on a subsequent test than those who received the base version of the game (without pretraining), yielding an effect size of 0.77. The third line of table 4.4 includes this study along with six others involving farming simulation, physics, and geology games, all favoring pretraining and yielding a median effect size of 0.77. This pattern supports the *pretraining principle of game design*: people learn better from games when they receive pregame instruction in the key components in the game.

Coaching principle of game design Once again, consider the *Circuit Game*. Suppose that, in the base version, the player goes through the levels of the game, solving circuit problems along the way, whereas in the enhanced version, the player receives explanative feedback after solving each problem. For example, in an experiment by Mayer and Johnson (2010), the explanative feedback involved presenting a box on the screen that contained a sentence stating the underlying principle based on Ohm's law. Adding explanations resulted in greater performance on a subsequent transfer test, yielding an effect size of 0.68. The fourth line of table 4.4 includes this study along with six others involving farming simulation, math, and health quiz games, with six of the seven experiments favoring adding coaching aids (such as explanations and advice) and yielding a median effect size of 0.68. This pattern supports the *coaching principle of game design*: people learn better from games when they receive explanations and advice as they play.

Self-explanation principle of game design One last time, consider the *Circuit Game*. Suppose that, in the base version, the player goes through the levels of the game, solving circuit problems along the way, whereas in the enhanced version, the player is prompted to explain the solution for each problem. For example, in a series of experiments by Johnson and Mayer (Johnson & Mayer, 2010; Mayer & Johnson, 2010), when the enhanced group selected a principle that explained their solution from a menu, this increased test performance (with a median effect size of 0.91 based on three experiments), but when the enhanced group was asked to type their explanation into a text box, this did not increase performance as compared to the base group (with an effect size of –0.06 based on one experiment). Thus, self-explanation may be most effective when it minimizes the mechanics of responding. The fifth line in table 4.4 includes these four experiments along with two others, yielding positive effects in all except one and a median effect size of 0.81. This pattern supports the *self-explanation principle of* *game design*: people learn better from games when they are prompted to explain their performance during the game.

Unpromising features: Immersion and redundancy In addition to the foregoing set of five promising principles, value-added research has tentatively identified two game design principles that do not appear to support learning. First, consider what happens when we convert the *Design-a-Plant* game from a desktop computer venue to immersive virtual reality, where players wear a head-mounted display and walk around and build a plant in three-dimensional space on the planet. In only two of six experiments did adding immersive virtual reality improve test performance, yielding a negative median effect size of –0.14, as shown in the sixth line of table 4.4 (Moreno & Mayer, 2002a, 2004). This pattern does not support the *immersion principle of game design*: people learn better from games when perceptual realism is maximized through immersive virtual reality. However, it should be noted that this conclusion is based on a single game studied in a single lab, and it remains for further research to determine whether immersive virtual reality may be useful when the learning objective involves navigating through space.

Second, consider what happens in the *Design-a-Plant* game when we present both printed and spoken words rather than solely spoken words. In two experiments, adding on-screen text to match Herman's spoken text resulted in poorer learning, yielding a negative median effect size of –0.23, as shown in the seventh line of table 4.4 (Moreno & Mayer, 2002b). This pattern does not support the *redundancy principle of game design*: people learn better from games when spoken words are supplemented with identical on-screen text. Again, this conclusion is limited by the fact that it is based on a single game studied in a single lab, and it remains for further research to determine whether redundancy improves learning under certain conditions.

Too-soon-to-tell features Mayer's (2014a) review also identified six principles of game design that did not yet have sufficient support by virtue of being based on four or fewer experiments and having small median effect sizes: competition (i.e., showing the score for competition or providing rewards based on score), learner control (i.e., allowing the player to determine the order of game levels), image (i.e., including static game characters on the screen), segmenting (i.e., breaking the material on the screen into parts or windows), choice (i.e., allowing the player to choose the format of how the screen looks), and narrative theme (i.e., incorporating an engaging story line). As the value-added research base grows, we will be in a better position to assess the efficacy of these features, but they appear to be unsettled for now.

Overall, the value-added approach to game research has proven to be useful in identifying game features that game designers may be encouraged to include or not include in their games. As the field is in its childhood, the most compelling conclusion is that it is becoming possible to base some decisions about game design on research evidence (Mayer, 2016).

Cognitive Consequences Research on Game-Based Learning

As depicted in figure 4.6 (adapted from Mayer, 2014a), in cognitive consequences experiments, participants play an off-the-shelf game for an extended period (experimental group) or engage in a control activity such as playing a completely different kind of game for the same period (active control group) or not playing any game (passive control group) and then take a test on the cognitive skill thought to be targeted in the game. In some cases, all participants take a pretest as well as a posttest, so the dependent measure is pretest-to-posttest gain.

This design is beginning to generate preliminary findings concerning which kinds of games cause improvements in which kinds of cognitive skills. Table 4.5 lists two promising cognitive consequences effects and seven unpromising ones, each of which are based on five or more experiments (adapted from Mayer, 2014a). The table provides a brief description of the type of game, the type of test, the median effect size, and the number of positive effects (out of the total number of experiments).

Promising effects As can be seen in the top two lines of table 4.5, the research literature on the cognitive consequences of game playing yields only two promising effects. First, there is strong and consistent evidence that playing first-person shooter games such as *Unreal Tournament* or *Medal of Honor* has positive effects on perceptual attention skills, such as those measured by useful field of view or multiple object tracking (Green & Bavelier, 2003, 2006; Mayer, 2014a). Positive effects were obtained in 17 of 18 experiments, yielding a median effect size greater than 1, which is considered a large effect. The effect of playing first-person shooter games on improving perceptual attention skills stands out as the strongest and most tested effect in the cognitive consequences literature.

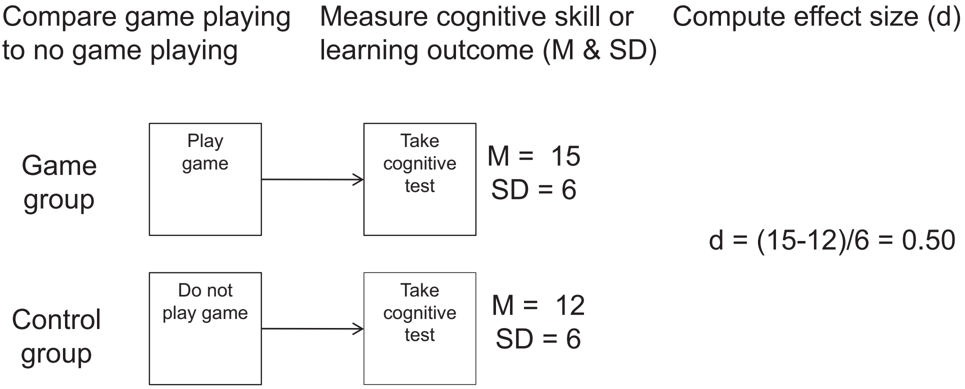


Figure 4.6
A cognitive consequences experiment.

Table 4.5
What are the cognitive consequences of playing off-the-shelf games?

Type of game	Type of test	Effect size	Number
Promising effects			
First-person shooter	Perceptual attention	1.18	17 of 18
Spatial puzzle	2-D mental rotation	0.68	11 of 11
Unpromising effects			
Spatial puzzle	Spatial cognition	0.04	9 of 15
Real-time strategy	Executive function	0.18	8 of 11
Real-time strategy	Perceptual attention	–0.10	4 of 9
Brain training	Spatial cognition	0.03	6 of 8
Spatial action	Perceptual attention	0.25	5 of 6
Brain training	Perceptual attention	0.31	4 of 5
Spatial puzzle	Perceptual attention	0.15	3 of 5

Second, there is also moderate and consistent evidence that playing the spatial puzzle game *Tetris* results in improvements in mental rotation tasks involving 2-D shapes, including *Tetris*-like shapes. Positive effects were obtained in 11 of 11 experiments, yielding a median effect size of 0.68, which is in the medium-to-large range. Interestingly, there is no strong evidence that playing *Tetris* has a positive effect on 3-D mental rotation, other spatial cognition skills, perceptual attention skills, or any other cognitive skills. For example, Sims and Mayer (2002) asked students to play *Tetris* (as exemplified in figure 4.7) for 10 sessions, but on a posttest the *Tetris* group did not outscore the control group on tests of reasoning, spatial cognition, or even mental rotation of non-*Tetris* shapes.

These two effects are consistent with what can be called the *theory of specific transfer of general skill* (Sims and Mayer, 2002; Singley & Anderson, 1989), in which a cognitive skill learned in a game domain can be applied to tasks outside the game that require the same cognitive skill. In a similar line of reasoning, Anderson and Bavelier (2011) have proposed that certain video games require players to exercise a targeted cognitive skill repeatedly in a variety of contexts and at increasingly challenging levels, which fosters learning of a cognitive skill that can be used outside the game environment. Accordingly, we would not expect game playing to improve cognitive performance in general, but rather we are on the lookout for games that require players to exercise a target cognitive skill repeatedly in varying contexts, at increasingly challenging levels, and for tests that are matched to the skill required in the game. The research evidence summarized in table 4.5 is consistent with this more focused view of the cognitive consequences of game playing.

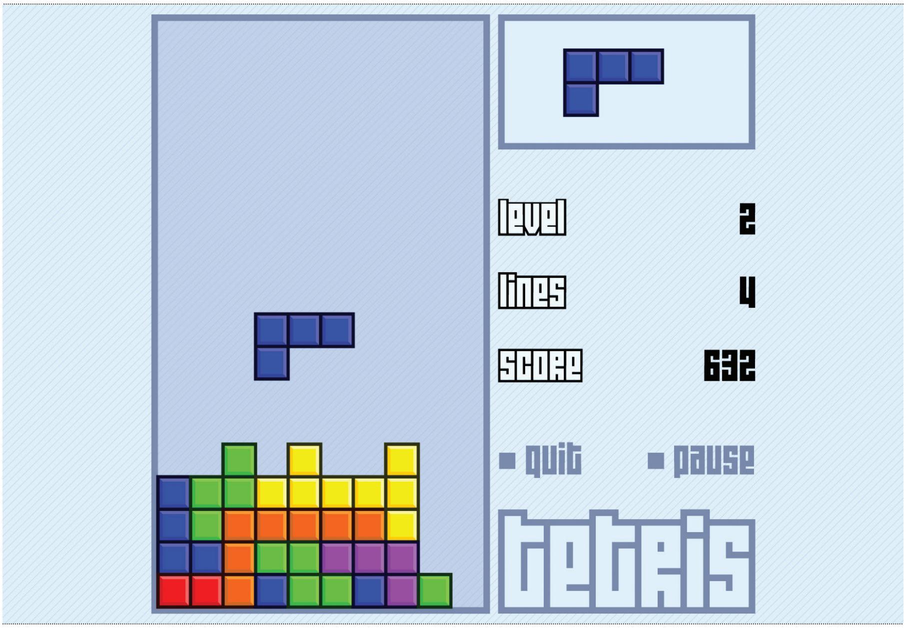


Figure 4.7
Screenshot from a game of *Tetris*.

Unpromising effects The bottom portion of table 4.5 lists seven effects that do not appear to be supported by research evidence because based on at least five experiments they could not produce an effect size greater than 0.40, which is considered the threshold for educational relevance (Hattie, 2009). As noted, playing the spatial puzzle game *Tetris* does not appear to affect performance on tests of spatial cognition skill or perceptual attention skill, perhaps because *Tetris* mainly requires exercising mental rotation skill. Real-time strategy games such as *Rise of Nations* do not appear to affect performance on perceptual attention tasks or executive function tasks, presumably because these games do not require repeated and varied practice on the cognitive tasks tested. Playing spatial action games such as *Super Breakout* or *New Super Mario Brothers* does not appear to have much effect on perceptual attention skills, perhaps because those skills are not the focus of the games. Finally, brain-training games such as *Brain Age* also appear to be ineffective in causing substantial changes in perceptual attention or spatial cognitive skills, perhaps because brain-training games cover a broad array of tasks without much variance in the context of practice.

Overall, cognitive consequences research yielding unpromising effects is consistent with research yielding positive effects: playing an off-the-shelf game can help players develop cognitive skills that apply outside the game only when the game requires

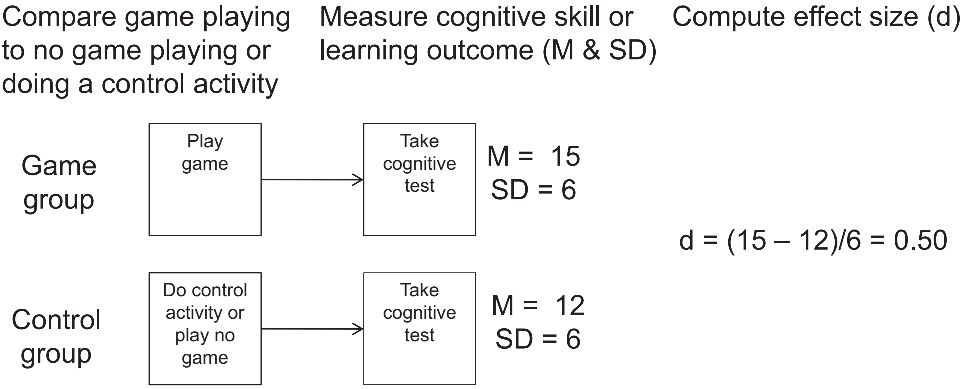


Figure 4.8

A media comparison experiment.

repeated practice on the targeted skill in a wide variety of contexts in the game and at increasingly challenging levels. An intriguing implication of cognitive consequences research is that it might be reasonable to design focused computer games that target a basic cognitive skill and provide for concentrated practice on a skill in a variety of contexts within the game. In short, the next generation of cognitive consequences research should include games that are specifically designed to teach targeted cognitive skills.

Media Comparison Research on Game-Based Learning

As depicted in figure 4.8, adapted from Mayer (2014a), in media comparison experiments participants learn academic material by playing a game (experimental group) or through conventional media such as a narrated slideshow, video, or illustrated text (control group) and then take a test on the material, preferably a transfer test that requires them to apply what they have learned.

This design is beginning to generate preliminary findings concerning when games might be more effective than (or just as effective as) conventional instruction. Table 4.6 summarizes effect sizes favoring learning from games for five academic content areas, based on a review by Mayer (2014a). The table provides the name of each content area, the median effect size favoring learning with games, and the number of positive effects (out of the total number of experiments).

As shown in table 4.6, the most promising content area for game-based learning is science, in which 12 out of 16 experiments yielded positive effects supporting games over conventional media, with a median effect size of 0.69, which is in the medium-to-large range. In contrast to the majority of studies represented in the first line of

Table 4.6
Is learning from games more effective than learning from conventional media?

Content area	Effect size	Number
Science	0.69	12 of 16
Second-language learning	0.96	4 of 5
Mathematics	0.03	3 of 5
Language arts	0.32	3 of 3
Social studies	0.62	2 of 3

Disconnect Copper Material from Door Electrical Panel

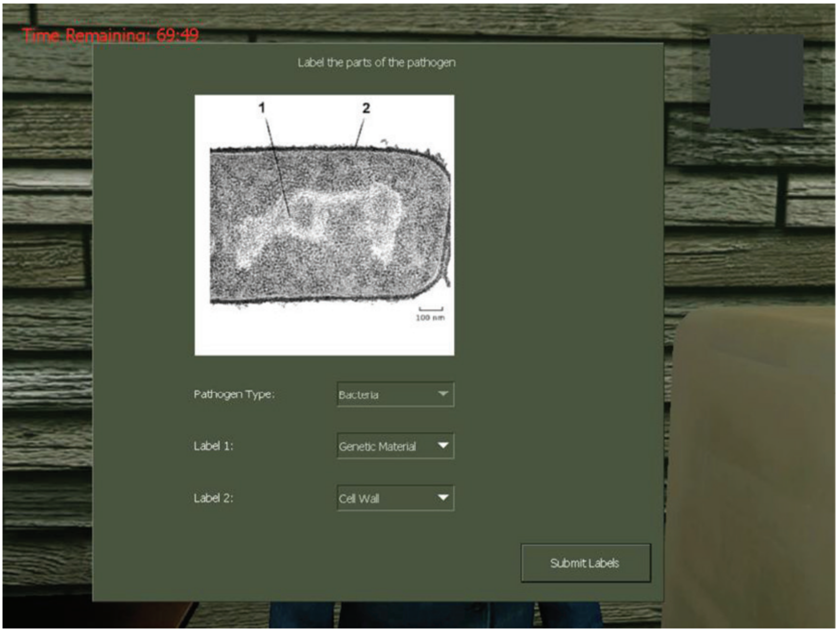
Disconnect Aluminum Material from Door Electrical Panel

What is a Wet-Cell Battery?

A wet-cell battery consists of two different metals partially submerged in a chemical solution (such as a **Brine Solution**). The metals are called electrodes, and the solution is called the electrolyte (see diagram below).

Figure 4.9
Screenshot from the action adventure game *Cache 17*.

table 4.6, Adams, Mayer, MacNamara, Koenig, and Wainess (2012) compared playing an action adventure game, *Cache 17*, in which college students learned to build a wet-cell battery to open a door in a search for lost artwork (as shown in figure 4.9), versus viewing a slideshow that conveyed the same information about wet-cell batteries. On a subsequent posttest on wet-cell batteries, the game group performed much worse than the slideshow group, with an effect size of –0.57 favoring the slideshow. Similar results were found in a study that compared playing an adventure game, *Crystal Island*, in which college students had to learn about infectious disease in order to end an



Time Remaining: 69:49

Label the parts of the pathogen

Pathogen Type: Bacteria

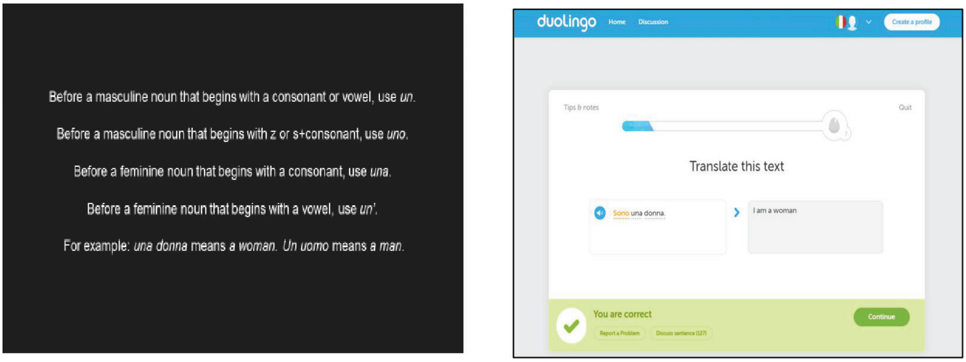
Label 1: Genetic Material

Label 2: Cell Wall

Figure 4.10
Screenshot from the adventure game *Crystal Island*.

epidemic (as shown in figure 4.10), versus viewing a slideshow that presented the same information about infectious disease (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012). In this case, the game group performed much worse than the slideshow group on a subsequent test about infectious disease, with an effect size of –0.31 favoring the slideshow group. Apparently, learning of core content is hindered when the activity in a game distracts the learner from the core academic material.

Second-language learning is the second most promising content area, with four out of five experiments yielding positive effects favoring games over conventional media and a median effect size of 0.96, which is a large effect. Thus, there is evidence that learning from games can be more effective than learning with conventional instructional media when the content involves certain topics in science and second-language learning. In a more recent study, James and Mayer (in press) asked college students to begin to learn Italian by playing the online language learning game *Duolingo* for seven sessions or by viewing the same material via seven slideshow presentations, as shown in figure 4.11. Learning with *Duolingo* resulted in only slightly better test performance than learning via slideshows (with an effect size of 0.25) but resulted in much higher ratings of enjoyment (with an effect size of 0.77). In both cases, students showed substantial improvements in learning Italian, given that they knew no Italian before they



Before a masculine noun that begins with a consonant or vowel, use *un*.

Before a masculine noun that begins with z or s+consonant, use *uno*.

Before a feminine noun that begins with a consonant, use *una*.

Before a feminine noun that begins with a vowel, use *un'*.

For example: *una donna* means *a woman*. *Un uomo* means *a man*.

Translate this text

Sono una donna.

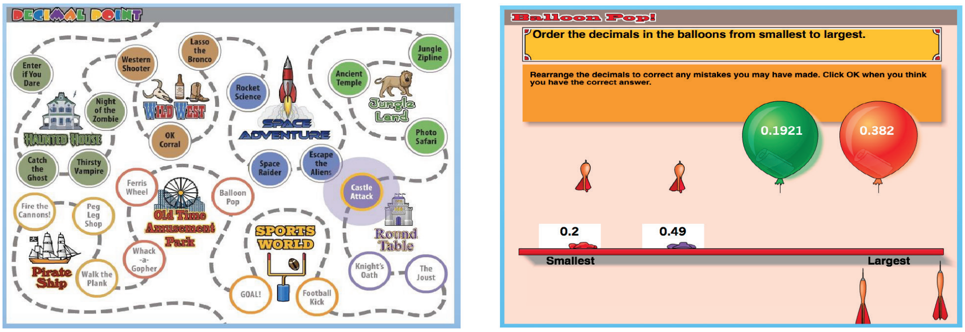
I am a woman

You are correct

Figure 4.11
Screenshots from slideshow (left panel) and the language learning game *Duolingo* (right panel).

started. Thus, if the game was only slightly more effective than, or even just as effective as, conventional instruction, this can be interpreted as support for game-based media, because students are more likely to choose to play a game and persist with it when they enjoy it more than conventional instruction.

Media comparison research in the content area of mathematics, based on five experiments, shows that games can be as effective as conventional media. Given the relatively low number of studies, it is premature to draw a firm conclusion. For example, in a recent study by McLaren, Adams, Mayer, and Forilizzi (2017), not included in table 4.6, middle school students learned about decimal fractions by playing a computer game called *Decimal Point*, in which they engaged with attractions that involved decimal fractions at an amusement park (as shown in figure 4.12) or by working on identical problems in a computer-based tutoring system. The game group performed better than the conventional group on an immediate test (with an effect size of 0.43) and on a delayed test (with an effect size of 0.37). This study is particularly relevant because the control group was matched closely to the experimental group in terms of having students in both groups solve exactly the same problems and get exactly the same feedback, and in terms of using the same computers to present material in both groups. Overall, further research will help determine whether math games can be superior to conventional instruction or simply equivalent in effectiveness. Even if they turn out to be equivalent, that can be a positive finding for game-based learning, because students are more likely to choose to play games in their spare time than to choose to take a tutorial lesson and are more likely to persist in learning with a game than from a conventional lesson. For example, in the *Decimal Point* study, students in the game group rated their experience as more enjoyable than did those in the tutorial group, with a large effect size of 0.95.



Order the decimals in the balloons from smallest to largest.

Rearrange the decimals to correct any mistakes you may have made. Click OK when you think you have the correct answer.

Figure 4.12

Screenshots from the computer game *Decimal Point*.

Finally, the last two lines in table 4.6 show that there is not yet sufficient evidence to draw firm conclusions about the effectiveness of games for language arts or social studies, but there certainly is no evidence to conclude that games are inferior to conventional media. The overall theme of table 4.6 is that learning from games is often more effective than learning from conventional media.

Media comparison research is subject to methodological and conceptual challenges (Clark, 2001). In terms of methodology, it is difficult for researchers to ensure that the game group and the control group are equivalent in terms of content and instructional method. In short, media comparison studies face the challenge of meeting the requirement of experimental control; that is, of creating game and control treatments that are the same for all features except the delivery medium. In terms of conceptual challenges, the results of media comparison studies should be interpreted in light of Clark's (2001) admonition that instructional media do not cause learning but rather instructional methods cause learning. In short, games may create affordances for instructional methods that cause learning, including instructional methods that are not easily afforded with conventional media.

How Are Cognitive Foundations Related to Affective, Motivational, and Sociocultural Foundations?

Although the focus of this chapter is on the cognitive foundations of game-based learning, a complete understanding of game-based learning also involves affective, motivational, and sociocultural factors.

First, concerning affective factors, research on the design of multimedia learning environments shows that students learn better from multimedia lessons that include emotional design elements, such as having the characters in an illustration show facial expression, have curved edges, and have appealing colors. For example, students performed better on a comprehension test after viewing a multimedia lesson on how immunization works when the main characters in the illustrations (such as a T cell and B cell) were changed from gray-tone geometric shapes into small faces with expressive eyes rendered in appealing colors (Plass, Heidig, Hayward, Homer, & Um, 2014; Um, Plass, Hayward, & Homer, 2012). Across three experiments, the effect sizes favoring emotional design of characters in the illustrations ranged from 0.43 to 0.61 to 0.77.

In a follow-up study, Mayer and Estrella (2014) compared learning about how a virus causes a cold from a multimedia slideshow in which the characters (such as a virus and host cell) were rendered as black and white shapes or as faces that portrayed human-like expressions such as surprise, fear, and sickness and were rendered in appealing colors. The emotional design group outperformed the control group on a transfer test, yielding effect sizes of 0.69 and 0.65 favoring the emotional design group. This line of research shows that features aimed at generating positive emotional responses from the learner can be just as effective in promoting learning outcomes as instructional features that are based on purely cognitive principles of multimedia design, as described by Mayer (2009). Research on emotional design with multimedia instructional messages has direct implications for the design of on-screen characters in games and exemplifies the fundamental role of affect in learning.

Second, concerning motivational factors, research on the design of multimedia instruction shows the benefits of adding features aimed at improving motivation. For example, in a study by Huang and Mayer (2016), students learned statistical concepts through worked examples in a computer-based instructional program. The lesson contained an on-screen pedagogical agent who either did or did not provide coping messages about how to manage students' feelings about their ability to learn the material, and expressive writing prompts that asked learners to type their thoughts and feelings about learning the material. Students who received lessons with these motivational features performed better on solving problems during learning (with an effect size of 0.71) and on a subsequent test on the material (with an effect size of 0.63) as compared to students who received the identical lesson without the motivational features. This line of research shows that adding features aimed at guiding motivation to learn can be just as effective as adding purely cognitive features based on principles of multimedia design, as described by Mayer (2009). Research on adding motivational features to online lessons has useful implications for the design of games and exemplifies the fundamental role of motivation in learning.

Third, concerning sociocultural factors, research on multimedia instruction shows the importance of determining how principles established in a lab setting work when they are incorporated into actual classroom settings. For example, although Mayer and his colleagues (Mayer 2009, 2014b; Mayer & Fiorella, 2014; Mayer & Pilegard, 2014) have made the case for 12 evidence-based principles of multimedia instructional design, most of the evidence comes from short-term laboratory studies that are devoid of sociocultural concerns. However, when researchers redesigned the PowerPoint slides used in a medical school course based on multimedia design principles, medical students in the course performed better on an immediate test (effect size 0.76) and a delayed test (effect size 1.17) covering the material as compared to medical students in the same course with the original slides. This line of research has useful implications for the generalizability of game research and exemplifies the importance of considering the social and cultural context of game-based learning. Relevant research topics include how to integrate games into school learning activities, how to expand learning time by including game playing at home, and how to involve groups or teams in game-based learning.

As research on affective, motivational, and sociocultural factors continues to develop, the model of game-based learning summarized in figure 4.4 should be expanded to include these factors. For example, Moreno and Mayer's (2007) cognitive-affective model of learning with media was an early attempt to incorporate affect, motivation, and metacognition into the cognitive theory of learning that is summarized in figure 4.4. More recently, Plass and Kaplan (2016) developed a model of learning with digital media that integrates cognitive and emotional factors. Advances in understanding the role of affective, motivational, and sociocultural factors are explored in the companion chapters in this part of this volume.

What Are the Implications for Design of Game-Based Learning?

When the goal of game design is to improve learning, it makes sense to take an evidence-based approach. Three fundamental questions in designing games that foster learning are:

1. Which features of a game work in promoting academic learning and which features do not (and under what conditions)? These questions are informed by value-added research. The research reviewed in this chapter offers some preliminary answers that support incorporating modality, personalization, pretraining, coaching, and self-explanation into games intended to foster academic learning.

2. Which kinds of games foster the development of which kinds of cognitive skills? In short, can playing an off-the-shelf game cause improvements in cognitive skills that are required to play the game? Is it possible to create focused games that teach targeted cognitive skills? These questions are informed by cognitive consequences research. The research reviewed in this chapter suggests that playing an off-the-shelf game may cause improvements in the cognitive skills that are required to play the game and that are exercised repeatedly in a variety of contexts and at increasingly challenging levels. So far, the research evidence shows that playing first-person shooting games such as

Unreal Tournament or *Call of Duty* can improve perceptual attention skills, and playing the spatial puzzle game *Tetris* can improve skill at mental rotation of two-dimensional shapes, including *Tetris*-like shapes. The lack of evidence for other cognitive consequences of game playing is consistent with the observation that most off-the-shelf games were intended for entertainment rather than education. Thus, a reasonable next step is to design focused computer games that target a particular cognitive skill and give players the chance to practice that skill repeatedly in a variety of contexts and at increasingly challenging levels.

3. Which learning objectives are best achieved with games rather than conventional media? Does it make sense to convert some traditional forms of instruction—such as computer-based tutorials, multimedia presentations, or even textbooks—into game-based forms of instruction? These questions are answered by media comparison research. The research reviewed in this chapter suggests that learning with games can be as effective or more effective than learning with conventional instructional media, particularly in the domain of science content. A reasonable next step is to examine more closely the conditions under which games are more effective than conventional media, and to incorporate game-based learning into schools and informal learning environments.

What Are the Limitations of Current Research and Directions for Future Research?

Overall, this chapter shows that we are making initial progress in answering these three fundamental kinds of questions about game-based learning and points the way to the following agenda for future research.

1. *Conduct replication studies*. The current research base is useful for drawing some preliminary conclusions but is still too small to yield many definitive conclusions. Replication studies are needed that examine the generalizability of our answers for the three core questions addressed in value-added research, cognitive consequences research, and media comparison research. This recommendation is consistent with one of Shavelson and Towne's six principles of scientific research in education: "Replicate and generalize across studies" (Shavelson & Towne, 2002, p. 4). Although some journal editors dismiss replication studies, this chapter shows how they are crucial for making progress in answering the core questions in our field. Given the increasingly important role of meta-analyses in our field (e.g., Hattie, 2009), replication studies are particularly relevant.

2. *Identify boundary conditions*. Current research is aimed at addressing basic issues such as which design features improve game-based learning, which kinds of games promote which kinds of cognitive skills, or which kinds of games are better than

conventional media. An important next step is to determine the conditions under which each effect is strong (or weak), including for which kinds of learners, on which kinds of learning objectives, and in which learning contexts. Research on multimedia instructional design, for example, shows that prior knowledge is an important boundary condition for several design principles in which the principles apply for learners with low prior knowledge but not for those with high prior knowledge (Kalyuga, 2014). It is worthwhile to pinpoint similar boundary conditions for design principles for game-based learning. One particularly useful boundary condition involves dosage—that is, how much exposure to a game is needed to produce learning? Another useful boundary condition concerns the age of the learners—that is, are the effects equally strong for elementary school students, middle school students, high school students, college students, and older adults?

3. *Broaden the context of study.* Most of the game studies reviewed in this chapter were short-term lab studies with immediate tests. Future research is needed that broadens the context of experiments to include more authentic learning environments such as in classrooms and informal learning situations. In short, we need to know whether we draw the same conclusions when game-based research is conducted in more naturalistic environments and over the long term. In addition, future research should expand the domain of study beyond existing design principles to explore evidence concerning emerging understudied areas of gaming such as situatedness, embodied cognition, scaffolding, and the like (Plass, Homer, & Kinzer, 2015).

4. *Focus on the learning outcome*. Some of the studies reviewed in this chapter had somewhat unfocused instructional goals. For example, it is probably unrealistic to expect game playing to have an impact on a wide variety of cognitive skills. Instead, future research is needed that examines games that are focused on improving a particular cognitive skill or helping students learn a particular piece of conceptual, procedural, or strategic knowledge. In short, future research is needed that is based on designing focused games that have a clear and measurable learning objective in terms of the knowledge or skill that is targeted.

5. *Focus on the learning processes*. Some current research uses self-reported surveys to assess players' cognitive processing during learning, but introspective reports can be problematic. Instead, future research is needed that examines cognitive processing during playing (such as measuring generative and extraneous cognitive load or affective and motivational processes) using measures that are more objective, including in-game behavior, eye tracking, EEG brain monitoring, and physiological monitoring. Focused assessments of cognitive processing during playing would be useful for testing theoretical predictions.

We are in the early days of shining the light of scientific research on game-based learning, but the progress to date is promising. Although visionaries will continue to make strong claims based on weak evidence, it falls on the scientific research community to continue to conduct rigorous, scientific research addressing the three core issues in game-based learning by using the value-added, cognitive consequences, and media comparison approaches. In short, the quest to use games for worthwhile educational purposes will be more successful to the degree to which it takes an evidence-based approach grounded in a cognitive theory of how people learn.

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5 Emotional Foundations of Game-Based Learning

Kristina Loderer, Reinhard Pekrun, and Jan L. Plass

Emotional Foundations of Game-Based Learning: The Basic "What" and "Why"

By some estimates, the average student will have spent 10,000 hours playing computer-based games by age 21—as much time as they will have spent at school (McGonigal, 2010). Therefore, taking advantage of students' motivation to engage in gaming to help them acquire knowledge seems to be an especially promising way to advance learning in the twenty-first century. However, the mechanisms underlying successful game-based learning (GBL) remain poorly understood. In this chapter, we focus on one important group of factors that likely shape digital GBL: learners' emotions.

Increasing learners' enjoyment and alleviating boredom are often advertised as major selling points of GBL. The National Foundation for Educational Research, for instance, lists "learning through intense enjoyment" as one of the constitutive features of digital GBL (Perrotta, Featherstone, Aston, & Houghton, 2013, p. 9). However, research shows that GBL involves not only enjoyment but also periods of frustration, boredom, or confusion (e.g., Conati & Gutica, 2016). Moreover, comparisons of GBL and non–game-based learning environments have produced mixed results with regard to their relative effectiveness in promoting enjoyment and reducing negative emotions (Rodrigo & Baker, 2011). At the same time, research indicates that emotions can strongly impact learners' processing of information as well as their motivation to learn, and, as a result, overall learning outcomes (Pekrun & Linnenbrink-Garcia, 2014a). Consequently, any comprehensive attempt to understand and harness the educational affordances of GBL will have to include its emotional foundations. Specifically, it requires consideration of *antecedents* of different emotions, including specific features of GBL environments (GBLEs), learner differences, and interactions between these variables, as well as *effects* of these emotions on learning.

This chapter provides a review of these emotional foundations of digital GBL. We first provide examples of emotion-relevant elements of GBL, using the well-studied intelligent game *Crystal Island* (Rowe, Shores, Mott, & Lester, 2011) as a case study. Next, we define emotion and discuss types of emotions relevant to GBL. We then offer an integrative model of the emotional foundations of GBL and use this model to review the extant literature. Finally, we derive implications for the design of emotionally sound GBLEs and outline directions for future research.

Incorporating Emotions into GBL: The Case of *Crystal Island*

Crystal Island (Lester, McQuiggan, & Sabourin, 2011) is an intelligent learning environment that leverages several components of the emotional pull of games for learning middle school biology. It centers on a narrative designed to lure players into the game and keep them emotionally engaged throughout the learning experience. Players take on the role of a medical field agent given the task of identifying and curing an infectious disease that has mysteriously befallen a team of researchers stationed on an island. This emotional immersion is supported by 3-D visuals depicting a volcanic island landscape as well as a host of lifelike embodied agents with which players interact in their quest to solve the medical mystery and save the infected patients (see figure 5.1).

Crystal Island seeks to foster autonomous, inquiry-based learning by allowing students to explore the island, collect clues, and test hypotheses by using virtual lab equipment to identify the contaminant at their own pace. These opportunities for self-directed learning are balanced with direct instruction through virtual personnel as well as a worksheet designed to scaffold learners' recording of information, hypotheses, and diagnoses (figure 5.2). The dynamic decision-network-based architecture of the game tracks and adapts to students' learning progress, providing informative feedback through pedagogical agents and action-contingent changes in the virtual world. These design features are aimed at sustaining curiosity and enjoyment while preventing boredom or frustration by providing sufficient challenge and facilitating mastery.

Recent work on *Crystal Island* has included automatic affect recognition and provision of affective support, which may entail changes in the GBLE (e.g., providing metacognitive prompts) or involve emotionally responsive, empathic agents (Lester et al.,

Figure 5.1
Crystal Island volcanic landscape and camp nurse with an infected patient in the virtual infirmary (Lester, Ha, Lee, Mott, Rowe, & Sabourin, 2013).

① Patient's Symptoms

Symptom A: Pain
Symptom B: Stomach Cramps
Symptom C: Vomiting
Symptom D: No entry

② Test Results

	I have tested:	The results showed:
Object A	Egg	Not contaminated
Object B	Orange	Not contaminated
Object C	Cheese	Not contaminated
Object D	Water	Not contaminated
Object E	No entry	No entry
Object F	No entry	No entry

③ Possible Explanations

	Likelihood:	Because:
Anthrax	Unlikely	Characteristics don't match
Botulism	No entry	No entry
Ebola	No entry	No entry
Influenza	Unlikely	Characteristics don't match
Salmonellosis	Possible	No entry
Smallpox	Very unlikely	Characteristics don't match

④ Final Diagnosis

Disease: No entry
Source: No entry
Treatment: No entry

Figure 5.2

Diagnosis worksheet for data collection and evaluation in *Crystal Island* (Lester, Ha, Lee, Mott, Rowe, & Sabourin, 2013).

2011). These agents mimic learners' emotions and signal understanding, or exhibit a different emotional state to enhance the learner's emotional condition. Thus, *Crystal Island* deploys a variety of strategies to promote emotions that are adaptive for learning and students' well-being. Similar principles have been incorporated in other GBLEs as well, including, for example, the motivationally enhanced game-based reading comprehension tutor *iSTART-ME* (Jackson & McNamara, 2013), the narrative-centered math game *Heroes of Math Island* (e.g., Conati & Gutica, 2016), or the simulation game *The Incredible Machine* (Sierra Online Inc., 2001), designed to teach various physics principles through interactive puzzles.

Constructs of Emotion

Definition of Emotion

Emotions constitute reactions to environmental (e.g., an exam situation) or person-internal events (e.g., recalling past experiences of an exam). They consist of multiple coordinated processes, which include (1) *affective components*, including subjective feelings (e.g., positive excitement connected to enjoyment); (2) *cognitive components*, consisting of emotion-specific thoughts (e.g., confidence in one's ability to solve a current task); (3) *physiological components*, supporting concomitant action (e.g., physiological activation for enjoyment); (4) *motivational components*, encompassing behavioral tendencies (e.g., tendencies to approach and invest effort in enjoyment); and (5) *expressive* *components*, including facial, postural, and vocal expression (e.g., speaking in a firm voice; Shuman & Scherer, 2014).

Classification of Emotions

Multicomponent approaches to emotion allow for distinguishing different emotions based on their component profiles (i.e., discrete emotions approach). From this perspective, emotions such as joy, pride, hope, anxiety, anger, or shame constitute distinct experiential states that serve specific cognitive, behavioral, and social functions. In contrast, dimensional approaches describe emotional experience based on a small number of affective dimensions. Valence (pleasant/positive, unpleasant/negative) and activation (activating, deactivating) have been proposed as the two most important dimensions for explaining variation in human affect (Russell, 1978). They can be viewed as higher-order factors for classifying discrete emotions as positive activating, positive deactivating, negative activating, or negative deactivating (table 5.1). In addition, emotions can be grouped according to their object focus; that is, the type of event at which they are directed (Pekrun, 2006). Object focus is important because it determines whether emotions pertain to the learning task at hand or not, thus influencing

Table 5.1

Valence × activation classification of learning-relevant emotions

	Valence	
Activation	Positive (pleasant)	Negative (unpleasant)
Activating	Enjoyment Hope Pride Gratitude Admiration Surprise[b] Curiosity	Anxiety Anger Frustration[a] Shame Envy Surprise[b] Confusion
Deactivating	Relief Contentment Relaxation	Disappointment Frustration[a] Boredom Sadness Hopelessness

Note: This classification is derived from established taxonomies of achievement emotions (Pekrun & Perry, 2014) and epistemic emotions (Pekrun et al., 2017).

[a] Frustration can comprise elements of (activating) anger and (deactivating) disappointment.

[b] Valence may vary based on the emotion-eliciting event (positive, negative).

their functions for learning. With regard to learning, including GBL, the following groups of emotions may be most important.

Achievement emotions are linked to activities or outcomes that are judged according to competence-based standards of quality. Emotions tied to achievement activities such as enjoyment or boredom during learning are referred to as *activity emotions*. Emotions that relate to success and failure outcomes are *outcome emotions*. These include prospective emotions such as anxiety or hope, focusing on future failures and successes, as well as retrospective emotions related to past achievement, such as pride, relief, shame, and disappointment.

Epistemic emotions are caused by cognitive qualities of task information and the processing of that information, such as surprise, curiosity, or confusion. They have been labeled epistemic because they pertain to epistemic aspects of cognitive activities, including knowledge acquisition (Brun & Kuenzle, 2008; Pekrun, Vogl, Muis, & Sinatra, 2017).

Social emotions include social achievement emotions, such as admiration or envy, that are related to the successes and failures of others, as well as social emotions, such as sympathy or hate, that pertain to the qualities of interpersonal relationships. In GBL, such emotions may arise when interacting with fellow learner-players (Brom, Šisler, Slussareff, Selmbacherová, & Hlávka, 2016) or game characters (Kim & Baylor, 2006). Both subgroups of emotions can influence learners' engagement (Linnenbrink-Garcia, Rogat, & Koskey, 2011).

Topic emotions are elicited by the contents covered by material to be learned. These may be of an empathic nature and, for instance, evoked by the fate of a virtual character. Other examples include emotions related to controversial scientific events, including anger and frustration when learning about climate change, for example, with the educational game *Mission Green* (Ghafi, Karunungan de Ramos, Klein, Lombana Diaz, & Songtao, 2011).

Aesthetic emotions are affective responses to the qualities of visual and performing arts (Scherer, 2005). Examples include awe, admiration, disgust, joy, or sadness, imbued, for instance, by specific musical arrangements (Silvia, 2009). Adaptive functions of these emotions involve experiencing pleasure, regulating arousal levels, or social bonding (Scherer & Coutinho, 2013). Aesthetic emotions are linked to peripheral elements of the environment but may nevertheless shape learning.

Technology emotions are responses to specific technology. Scholarly interest in these emotions can be traced back to the 1990s and the spread of information technologies into educational, organizational, and private realms. The initial focus was on computer anxiety (Powell, 2013) and resulted in the development of emotionally grounded models of technology use and acceptance (Davis, 1989) that are still relevant in today's media-saturated societies (consider, for instance, experiences of frustration caused by limited internet speed; see Butz, Stupnisky, & Pekrun, 2015). Technological advances and increasing functional complexity may thus induce both positive and negative emotions toward the learning environment that, in turn, influence task-related engagement.

Learners may also be experiencing *incidental emotions* that are triggered by events outside the learning environment (e.g., disputes with siblings). While these are not directly tied to learning, they may nevertheless shape learners' engagement in a task. For instance, an individual experiencing negative emotions may have difficulty focusing on the task at hand.

For most emotions, object focus may vary. For example, frustration may be triggered by perceptions of personal incompetence (achievement focus), cognitive incongruity resulting from an unsolved task (epistemic focus), contents such as manmade pollution (topic emotions), or ongoing hindrances in using the digital interface to interact with a learning game (technology focus). As such, attending to the object focus of emotions is also pivotal for a deeper understanding of the emotional impacts of different GBLEs.

Emotional Foundations of GBL: An Integrative Framework

As illustrated, GBL is laden with a multitude of emotions that may relate to different aspects of the learning situation. In this section, we propose an integrative model of emotional foundations of GBL that aims to take this emotional diversity into account while highlighting common mechanisms of these emotions that can guide the design of emotionally sound GBLEs (see figure 5.3). The basic structure of this model is provided by the control-value theory (CVT) of achievement emotions (Pekrun, 2006; Pekrun & Perry, 2014), a platform for research on emotions and learning across different research paradigms and educational environments. We extend this framework to other groups of learning-relevant emotions by considering the emotional impact of cognitive incongruity (Graesser, D'Mello, & Strain, 2014; Muis, Pekrun, et al., 2015), Plass and Kaplan's (2016) integrated cognitive affective model of multimedia learning (ICALM), and the intelligent tutoring and games framework (ITaG; McNamara, Jackson, & Graesser, 2010), which systematizes affective functions of GBLE features. We first address the antecedents of emotions in GBL, then discuss their functions for learning, and finally deduce principles for designing GBLEs from an emotional perspective.

Antecedents of Emotions in GBLEs

Emotions can be stimulated by different factors. Our model considers two groups of proximal factors that may be particularly important in GBLEs: (1) appraisals of the self and situational contingencies (arrow 1 in figure 5.3) and (2) emotional transmission from (actual or virtual) peers or instructors as well as other GBLE features (e.g., musical score, arrow 2 in figure 5.3). The influence of distal factors such as learner characteristics and GBLE features are thought to be mediated by these factors.

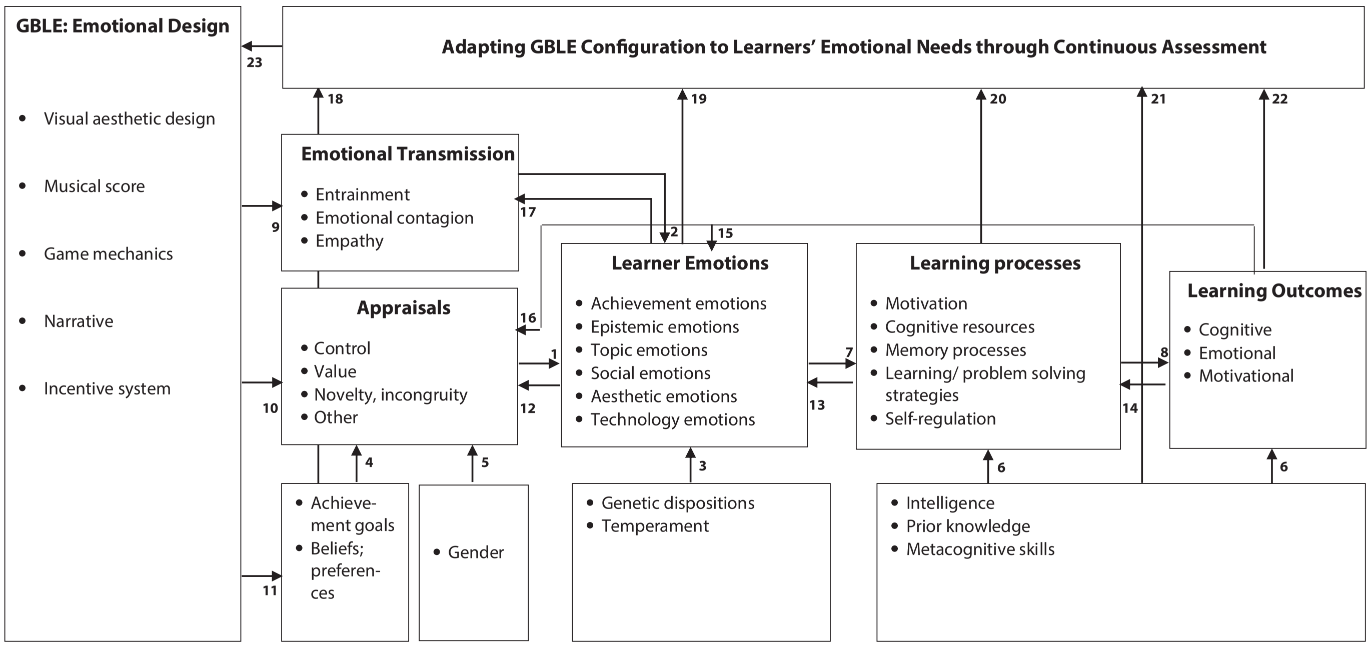

Figure 5.3
Integrative model of emotional foundations of GBL.

Proximal antecedents: appraisal processes Appraisal theories postulate that "usually, people's emotions arise from their perceptions of their circumstances" (Ellsworth & Scherer, 2003, p. 572). Appraisals are critically important in preparing adaptive thought and action via emotion in settings that are shaped by cultural evolution and thus require careful interpretation of situational demands, such as learning and achievement settings. Depending on the type of emotion, appraisals can relate to different aspects of an event.

Achievement emotions According to the CVT, achievement emotions are determined by the perceived controllability and value of achievement activities and outcomes. *Perceived control* pertains to the extent to which one is in command in a given achievement situation, as implied by causal expectancies regarding future tasks (self-efficacy and outcome expectations), causal attributions of success and failure, and competence appraisals (e.g., self-concepts of ability; see Pekrun, 2006). *Perceived value* includes subjective importance (e.g., stemming from interest or instrumental usefulness) as well as direction (positive vs. negative; i.e., goal congruence in terms of events either supporting or impeding goal attainment). Rewards or punishments are key game elements that shape achievement values and related emotions. The lowered emphasis of failure in GBLEs as compared with classroom-based achievement situations may also impact learners' value perceptions by shifting the focus from avoiding failure to embracing mistakes as a natural part of learning, which we have described as graceful failure (Plass, Homer, & Kinzer, 2015).

The CVT posits that achievement emotions are a joint function of perceived control and value (table 5.2). For outcome emotions, expectancies (prospective outcome emotions; e.g., hope or anxiety) and attributions (retrospective outcome emotions; e.g., pride or shame) are considered important. However, retrospective joy, sadness, or frustration may be directly induced by perceived successes or failures (Weiner, 1985). For activity emotions, appraisals of personal competence as well as value are seen as primary antecedents. Both sufficient control and positive value are required for positive achievement emotions, whereas negative achievement emotions are linked to appraisals of low control and sufficient negative value. Boredom, in contrast, is linked to lack of either positive or negative value (see the summary of supporting evidence in Pekrun & Perry, 2014; see also Putwain et al., 2018, for recent empirical support of these assumptions).

Epistemic emotions Epistemic emotions arise when tasks produce cognitive incongruity; for instance, by presenting unexpected, contradictory, or complex information (e.g., Vogl, Pekrun, Murayama, & Loderer, 2019). In the game *Operation ARIES!* (Millis et al., 2011), designed to teach scientific critical thinking, learners engage in trialogues with an expert agent and a peerlike student agent to discuss the methodological qualities of empirical studies. To induce incongruity, the agents are staged to disagree on

Table 5.2
Typical appraisal combinations for major achievement emotions

		Appraisal	
Emotion	Typical scenario	Control	Value
Prospective outcome emotions			
Joy	High expectation of success	High	Positive
Hope	Uncertain expectation of success	Moderate	Positive
Anxiety	Uncertain expectation of failure	Moderate	Negative
Hopelessness	Low expectation of success or high expectation of failure	Low	Positive/ negative
Retrospective outcome emotions			
Joy	Success	Irrelevant	Positive
Sadness	Failure	Irrelevant	Negative
Relief	Unexpected success	Low	Positive
Disappointment	Unexpected failure	Low	Negative
Pride	Success caused by internal factors	Internal	Positive
Shame	Failure caused by internal factors	Internal	Negative
Gratitude	Success caused by others' actions	External	Positive
Anger	Failure caused by others' actions or one's own lack of effort	External/ internal	Negative
Activity emotions			
Joy	Positive evaluation of current task	High	Positive
Anger	Negative evaluation of current task (e.g., as aversively requiring effort)	High	Negative
Frustration	Current task involves obstacles	Low	Negative
Boredom	Current task is either insufficiently or exceedingly challenging	High or low	None

Note: Value refers to the valence of the emotion-eliciting event, with positive = pleasant activity/ positive outcome (success) and negative = unpleasant activity/negative outcome (failure). For hopelessness, the focus may either be on unattainable success (positive outcome) or unavoidable failure (negative outcome).

Adapted from Pekrun (2006).

their evaluations of study designs. A typical sequence of epistemic emotions experienced in this context can include (1) surprise over the agents' disagreement, (2) curiosity if surprise is not fully dissolved, (3) confusion if incongruity increases as both game agents provide compelling arguments, (3) anxiety in the case of severe incongruity and information that disturbs existing beliefs, (4) enjoyment when the problem is solved, or (5) frustration or boredom when cognitive equilibrium cannot be restored (Graesser et al., 2014).

In addition to cognitive incongruity, epistemic emotions can be linked to changes in learners' control-value appraisals. Perceptions of epistemic control can derive from the degree of complexity and uncertainty ascribed to cognitive tasks embedded in the learning game, as well as one's perceived ability to cope with this complexity and overcome uncertainty. The extent to which activities are judged to be important and either stimulating (positive) or aversive and uninteresting (negative) contributes to the perceived epistemic value of the in-game activities.

Social emotions Control-value appraisals may also contribute to the arousal of social emotions. Weiner (1985, 1995) proposed that an individual should experience envy over another's success if they attribute this success to that person's (uncontrollable) ability rather than their (controllable) effort. This approach can be extended by considering the individual's self-directed appraisals of control. Specifically, individuals may envy others for their successes if they perceive their own control over their achievement to be low. In this constellation, others' successes or one's personal failures are often viewed as undeserved (Feather, 2006). In contrast, if others' successes are perceived as deserved, admiration may be triggered.

If another person fails, sympathy or compassion may arise if the individual feels in control over their own achievement while perceiving the other person as lacking control, undeservingly. Perceiving others' failures as deserved, however, may evoke schadenfreude (i.e., joy over another's misfortune). Such emotions may be particularly relevant in GBLEs in which students compete with other learners or virtual agents or are at least aware of each other's progress and game score as in the competitive variant of *Factor Reactor*, a game designed to train arithmetic fluency in middle school students (Plass et al., 2013).

Learning may also involve social emotions beyond achievement. Socially oriented appraisals underlying relationship-focused emotions may also involve control and value. These are likely linked to perceptions of status (i.e., acceptance vs. rejection) in the case of internally directed control appraisals, responsibility and intention in the case of external control, and general like versus dislike of others and the importance attached to specific relationships (Hareli & Parkinson, 2008). Such affiliative affect may be brought into GBL contexts through real-life or virtual interactions between learners who already know each other. They can also arise in GBLEs that include more extensive social interaction, for instance to enhance conceptual learning through joint elaboration (Meluso, Zheng, Spires, & Lester, 2012) or to train social-emotional skills (Nikolayev, Clark, & Reich, 2016).

Topic emotions and aesthetic emotions Appraisal antecedents of these emotions have been less studied. Recent work on emotions in science learning has emphasized learners' individual interest toward topics (Hidi & Renninger, 2006) in shaping perceived value. Positive values of a topic should foster positive emotions such as enjoyment, whereas negatively valued topics may trigger content-related anxiety (e.g., when learning about potential consequences of sociopolitical conflicts) or anger (e.g., when firm believers of creationism are confronted with evolutionary perspectives). Individuals' convictions regarding the (un)controllability of such events likely also play a role in the arousal of topic-related emotions, as suggested by studies examining students' learning about environmental issues in hypermedia environments (e.g., Zumbach, Reimann, & Koch, 2001).

Aesthetic emotional experience has also been conceptualized as a matter of personal perception. Important evaluative dimensions are intrinsic pleasantness (e.g., sensory consonance or harmony versus dissonance), controllability of the design (e.g., options for adjusting color schemes to one's preferences), and novelty. GBLE designs evaluated as pleasant, stimulating, and controllable are linked to increased positive emotions, whereas the opposite pattern is characteristic of negative aesthetic emotions (Silvia, 2005).

Technology emotions Personal control over and value of digital tools also impact learners emotionally. Many factors can influence perceived controllability of technological devices, including design elements that either facilitate or hinder ease of navigation. In combination with perceived utility versus inadequacy of technology, control is expected to prompt different emotions in similar ways as it influences achievement emotions (table 5.2). For example, technology-related enjoyment is linked to high control and high positive value (e.g., usefulness), whereas lower levels of control and lack of value assigned to technology are likely precursors of negative emotions such as anxiety or frustration (Butz et al., 2015).

Empirical evidence Barring differences in the specific referents of appraisal, we suggest a common control-value appraisal pattern across different groups of emotions: subjective control is posited to alleviate negative emotions and strengthen positive ones, while ascriptions of personal importance should generally intensify emotional experiences. Boredom is seen as an exception, as it can involve perceptions of excessive personal control and is typically intensified by lack of value (Pekrun, 2006).

Classroom-based research has confirmed that perceived control over learning relates positively to students' enjoyment, hope, and pride and negatively to their anger, anxiety, shame, hopelessness, and boredom (see the reviews in Pekrun & Perry, 2014; Pekrun, 2018). Similar links have been found for students enrolled in online courses (Artino, 2009; Marchand & Gutierrez, 2012) or interacting with multimedia (Stark, Malkmus, Stark, Brünken, & Park, 2018) as well as virtual reality environments (Noteborn, Bohle Carbonell, Dailey-Hebert, & Gijselaers, 2012). The perceived value of learning is positively related to both positive and negative emotions, except boredom (e.g., Artino & Jones, 2012), confirming that the importance of success and failure amplifies these emotions except for boredom. Initial evidence suggests that the relevance of control-value appraisals extends to emotions in GBLEs (Sabourin & Lester, 2014).

Similarly, studies on epistemic emotions during learning have reported positive associations between perceived epistemic control and curiosity as well as enjoyment, and negative associations with confusion, frustration, and boredom (Muis, Psaradellis, et al., 2015). Task value correlated positively with curiosity and enjoyment and negatively with boredom (Muis, Psaradellis, et al., 2015; Pekrun et al., 2017). These relations of perceived competence and value with curiosity or confusion have also been observed within *Crystal Island* (Sabourin & Lester, 2014). Furthermore, several studies support the proposed role of control and value in the elicitation of social achievement emotions (e.g., Rudolph & Tscharaktschiew, 2014). Finally, Butz et al. (2015, 2016) gathered evidence for the appraisal profiles of technology emotions. Perceptions of control and usefulness of technology related positively to enjoyment of technology use and negatively to anxiety, anger, and boredom.

Taken together, research corroborates the relevance of control-value appraisals for different groups of emotions. Most of the available evidence stems from research involving learning that is not game based. However, basic functional mechanisms of emotions, including their appraisal structures, are posited to generalize across different learning settings (see section on contextual specificity versus relative universality of emotions). A recent meta-analysis of emotions in technology-based learning environments supports this claim (Loderer, Pekrun, & Lester, 2018). Mean correlations between control-value appraisals and emotions followed the theoretically expected patterns and remained fairly robust across different types of environments.

Proximal antecedents: emotional transmission Pathways to emotion include affective attunement to sensory input (e.g., pictures, music) as well as emotions displayed by others. Scherer and Coutinho (2013) distinguish three types of emotional transmission: entrainment, contagion, and empathy (arrow 2 in figure 5.3).

Entrainment has been defined as "the process through which two physical or biological systems become synchronized by virtue of interacting with each other" (Trost, Labbé, & Grandjean, 2017, p. 96). Research has focused on synchronization of autonomic physiological (e.g., cardiac activity) and sensorimotor processes (i.e., movement) with external auditory rhythms of musical pieces (e.g., beat, tempo). Entrainment subconsciously drives changes in emotions by influencing physiological and motor-expressive components, a mechanism that may be particularly pertinent to the arousal of aesthetic emotions (Scherer & Coutinho, 2013). Importantly, this mechanism may help explain previously observed effects of musical score on videogame players' (e.g., Hébert, Béland, Dionne-Fournelle, Crête, & Lupien, 2005; Lipscomb & Zehnder, 2004; see also Eich, Ng, Macaulay, Percy, & Grebneva, 2007) and learners' (Dickey, 2015) emotions.

Emotions can also be "caught" directly from external stimuli by means of *emotional contagion*. Emotional contagion constitutes a largely unconscious process driven by observation and automatic mimicry of expressive cues of others (e.g., facial expression;

see Hatfield, Cacioppo, & Rapson, 1994). Emotional contagion is likely an important driver of convergence between teacher and student emotions in the classroom (Frenzel, Becker-Kurz, Pekrun, Goetz, & Lüdtke, 2018). Such contagion may also occur in GBLEs. An example is collaborative learning games that allow social interactions with fellow learners supported by video or voice chat (Admiraal, Huizenga, Akkerman, & ten Dam, 2011). Similarly, emotions expressed by digital agents may carry over to learners (Gratch & Marsella, 2005). For example, Krämer et al. (2013) showed that participants interacting with smiling agents smiled longer than those interacting with nonsmiling agents.

In digital and game-based learning, empathy has been examined for empathic environments that automatically infer and respond to learners' emotions through agents' emotional displays (D'Mello & Graesser, 2012; McQuiggan & Lester, 2007). Conversely, learners may attempt to understand emotions expressed by others. For instance, bored learners may be intrigued by agents overtly enjoying a task and feel into this positive emotion by decoding and reenacting its underlying appraisals. Similarly, in collaborative GBL, learners may share their peer's expressed frustration at not being able to solve a task (Järvenoja & Järvelä, 2005).

Distal antecedents: learner characteristics Individual characteristics of learners may influence their emotional experiences during GBL. This includes physiologically bound temperament (arrow 3 in figure 5.3; see also Stemmler & Wacker, 2010). Other central factors are learners' achievement goals, implicit theories of intelligence, epistemic beliefs, aesthetic preferences, gender, and cognitive abilities (arrows 4–6 in figure 5.3).

Mastery-approach goals focused on task mastery and personal improvement should direct learners' attention toward the controllability and positive values of learning activities, thus fostering enjoyment of learning and reducing boredom. In contrast, *performance-approach goals* focused on outperforming others should direct attention toward positive outcome appraisals, and *performance-avoidance goals* focused on avoiding being outperformed by others should shift attention toward negative outcome appraisals, thus facilitating positive or negative outcome emotions, respectively. These relations have been observed in traditional classroom settings (Pekrun, Elliot, & Maier, 2006) and in online courses (Yang & Taylor, 2013). Few studies have examined the role of achievement goals for learners' emotions in GBLEs (for an exception, see McQuiggan, Robison, & Lester, 2010).

Learners' *implicit theories of intelligence* (Dweck & Leggett, 1988) are thought to influence subjective control over learning and thus the arousal of emotions. Learners who believe that ability is malleable (incremental theorists) exhibit higher subjective control than learners who view ability as a fixed, inborn trait (entity theorists; King, McInerney, & Watkins, 2012). Initial research indicates that positive emotions in digital learning and GBL are linked to incremental beliefs, and negative emotions, such as anxiety, are linked to entity beliefs (Arroyo, Burleson, Tai, Muldner, & Woolf, 2013; Tempelaar, Niculescu, Rienties, Gijselaers, & Giesbers, 2012).

Gender is expected to influence appraisals and emotions based on gender stereotypes regarding competencies in different subject domains. For example, females typically report less enjoyment and more anxiety, shame, and hopelessness in mathematics than males do (Chang & Beilock, 2016; Frenzel, Pekrun, & Goetz, 2007). These differences were driven by differences in control-value appraisals, with females reporting lower competence beliefs and less intrinsic value of mathematics (Frenzel, Pekrun, & Goetz, 2007). These patterns have also been obtained with learners taking online mathematics and statistics classes (Tempelaar et al., 2012) or interacting with gamified intelligent math tutoring systems (Arroyo et al., 2013).

Gender stereotypes may also explain differences in technology emotions considering that technology is still largely viewed as a male domain. Girls still report significantly less experience with as well as enjoyment of computers and GBL (Admiraal et al., 2014). Gender may also be linked to preferences for game design. Girls have been found to prefer narrative development and cooperative games, whereas boys tend to prefer games with competitive elements (Admiraal et al., 2014). However, while preadolescent boys spend significantly more time (up to 13 hours per week) playing games than girls do, many girls also favor stereotypically male videogame genres, including first-person shooter games, suggesting that traditional gender differences may be disappearing (Homer, Hayward, Frye, & Plass, 2012).

Epistemic beliefs regarding the nature of knowledge and knowing influence the arousal of epistemic emotions (Muis, Pekrun, et al., 2015). Cognitive incongruity arising from misalignment between individuals' beliefs and the cognitive quality of a specific learning task may increase perceptions of value resulting from novelty but decrease perceived control, which should give rise to different emotions (Trevors, Muis, Pekrun, Sinatra, & Muijselaar, 2017). Accordingly, when confronted with learning material presenting divergent views on a topic, individuals who view knowledge as consisting of definite information determined by a single authority are likely to experience surprise, confusion, anxiety, or frustration. In contrast, those who endorse constructivist beliefs and view knowledge as complex and requiring careful evaluation may experience curiosity and enjoyment (Muis, Pekrun, et al., 2015). As such, GBLEs may differ in their epistemic appeal to individuals.

Individuals may also differ in their *aesthetic preferences* regarding color schemes or musical arrangements (Plass & Kaplan, 2016; Street, Forsythe, Reilly, Taylor, & Helmy, 2016) that influence how they respond emotionally to GBLE design. Recent research has also sought to identify links between aesthetic emotions and personality traits. Fayn, MacCann, Tiliopoulos, and Silvia (2015) showed that individuals higher on the Big Five trait "openness to experience" are more likely to experience interest when confronted with novel or unusual design elements.

As *cognitive ability* and *prior knowledge* influence achievement, they facilitate positive achievement emotions and reduce negative ones. This link may be mediated by the impact of success and failure on appraisals of control and value (Reeve, Bonaccio, & Winford, 2014). Similarly, prior experience with technology typically shows positive relations with positive technology-focused emotions such as enjoyment and negative relations with negative technology-focused emotions (e.g., Cheung & Sachs, 2006).

Distal antecedents: emotional design of GBLEs Our model posits that characteristics of GBL can affect learners' emotions by influencing their appraisals, by emotional transmission, and by shaping their beliefs (arrows 9–11 in figure 5.3). This opens a wealth of possibilities for creating emotionally sound GBLEs, which we will discuss. As design decisions should be guided by knowledge regarding adaptive and maladaptive functions of emotions for GBL, we first examine how different emotions may foster or impede learning with games.

Functions of Emotions for GBL

Both the cognitive-motivational model of emotion effects that is part of the CVT (Pekrun, 2006) and the ICALM (Plass & Kaplan, 2016) argue that emotions impact learning outcomes through cognitive and motivational mechanisms (arrows 7 and 8 in figure 5.3). This idea is grounded in research showing that affective states influence learning-relevant cognitive processes such as allocation of attention, memory storage and retrieval, and problem solving, as well as motivational tendencies and behavior (Barrett, Lewis, & Haviland-Jones, 2016). We consider four mechanisms that are of particular importance.

Motivational processes Positive activating emotions (table 5.1) can mobilize motivational energy and fuel learning. Specifically, enjoyment and curiosity during gameplay can reinforce investment of effort in learning tasks (e.g., Vogl et al., 2019). Positive outcome emotions such as pride of having mastered a difficult task and subsequently feeling hopeful in tackling the next game level can also provide powerful sources of motivation to learn. This may apply to positive social achievement emotions as well, such as admiring others.

Negative motivational effects are expected for negative deactivating emotions such as boredom aroused by monotonous narrative structures of GBLEs, or hopelessness emerging from repeated failures to complete tasks and proceed through the game. Boredom especially may increase tendencies to engage in off-task behavior such as playing around with personalization features of one's game avatar (Snow, Jackson, Varner, & McNamara, 2013) or gaming the system; that is, attempting to "succeed in an educational environment by exploiting properties of the system's help and feedback rather than by attempting to learn the material" (Baker et al., 2008, p. 186). Gaming the system to avoid learning is commonly observed not only in intelligent tutoring systems or online course formats but also in learning games intended to engage students through fun activities and aesthetically appealing design (Baker, D'Mello, Rodrigo, & Graesser, 2010; Loderer et al., 2018).

Positive deactivating and negative activating emotions often have variable motivational effects. Positive deactivating emotions such as relief over unexpected success can undermine immediate motivation to invest effort but may reinforce commitment to individuals' achievement goals and reengagement with the learning task in the long term. Negative activating emotions such as anxiety and shame can undermine intrinsic motivation to learn but can induce strong extrinsic motivation to increase effort and avoid failure, which has been observed both in the classroom (Turner & Schallert, 2001) and across various digital learning environments (Loderer et al., 2018). Anger or envy in response to others' achievements may also motivate students to learn more and outperform peers.

Cognitive resources Resource allocation models of emotion (Ellis & Ashbrook, 1988), as well as cognitive load theory (Sweller, 1994), suggest that emotions impose an extraneous cognitive load; that is, they make demands on working-memory resources, which are then not available to perform complex tasks. The CVT and ICALM propose a more nuanced view that considers the object focus of emotions. Emotions with task-external referents, such as joy over weekend plans or frustration about nonfunctioning technology, disrupt attentional focus. In contrast, enjoyment or curiosity targeted at the learning activity may focus attention on task completion. Multimedia learning studies employing eye tracking to measure attention indicate that positive emotions induced via autobiographical recall prior to learning can distract attention and undermine learning (Knörzer, Brünken, & Park, 2016). However, positive states induced through visual elements of multimedia environments can reduce self-reported cognitive load (Plass, Heidig, Hayward, Homer, & Um, 2014; Um, Plass, Hayward, & Homer, 2012) and sustain attentional focus on relevant information (Park, Knörzer, Plass, & Brünken, 2015). Recent work has also shown that decorative pictures accompanying instructional texts in multimedia learning environments can be beneficial for learning when pictures have a positive affective charge and are strongly connected to the content of the material to be learned (Schneider, Dyrna, Meier, Beege, & Rey, 2018).

These positive effects stand in contrast to negative effects *seductive details* have on learning gains (e.g., Lehman, Schraw, McCrudden, & Hartley, 2007). One explanation for positive effects of some features of aesthetic design may be that these features prompt low-intensity positive moods that boost learners' motivation to stay focused without distracting attention away from relevant material (Park, Flowerday, & Brünken, 2015).

Memory processes and learning strategies Emotions facilitate different modes of processing contents covered by GBLEs. Experimental mood research indicates that positive states promote top-down, relational, and flexible processing, whereas negative states lead to bottom-up, analytical, and more rigid thinking (Fiedler & Beier, 2014). One implication is that emotions impact storage and retrieval of learning material. While positive emotions can lead to enhanced integration of information in memory, negative states can increase precision in processing single units of information (Spachtholz, Kuhbandner, & Pekrun, 2014; see also Kuhbandner & Pekrun, 2013, for affective influences on retrieval-induced forgetting). This is likely to be the case during GBL as well.

Accordingly, positive activating emotions should promote the use of flexible and deep learning strategies such as elaboration, organization of material, or critical thinking. However, select negative activating emotions such as confusion may also catalyze critical thinking and elaborative processing as a means of reducing cognitive incongruity during gameplay. Negative activating emotions such as anxiety or shame, in turn, should primarily facilitate rigid rehearsal of material. In contrast, deactivating emotions can undermine any strategic efforts, yielding superficial processing. This may be particularly true for negative deactivating emotions such as boredom or hopelessness.

Supporting evidence can be found not only for emotions in traditional learning environments (Pekrun & Linnenbrink-Garcia, 2014a) but also in digital learning environments (Artino & Jones, 2012; Loderer et al., 2018; Plass et al., 2014; Um et al., 2012). For GBL, Sabourin and Lester (2014) showed how students' emotions related to their inquiry strategies in solving *Crystal Island*'s mystery. Students reporting enjoyment and curiosity engaged in more effective problem solving by gathering goal-relevant information and testing meaningful hypotheses as compared with learners who experienced frustration or boredom. Curiosity was positively related and boredom negatively related to problem-solving efficiency (i.e., number of lab tests conducted, time taken to deduce the solution).

Self-regulation of learning Self-regulation requires flexibility to adapt thought and action to task demands and individual goals (Azevedo, Johnson, Chauncey, & Burkett, 2010). This is particularly important in GBLEs that put learners in charge of managing their own learning, for instance by providing open-ended environments. Because positive activating emotions promote flexible strategy use, they are expected to facilitate self-regulation of learning. Negative emotions, such as anxiety or shame, in turn facilitate reliance on external guidance. In contrast, negative deactivating emotions likely reduce overall engagement in learning. Accordingly, enjoyment and curiosity have been found to relate positively, and boredom to relate negatively, to learners' self-regulation (Artino & Jones, 2012; Muis, Psaradellis, et al., 2015; Pekrun et al., 2002).

Learning outcomes Given the multifaceted impact of emotions on various functional mechanisms of learning, their effects on overall learning outcomes are inevitably complex. Net effects likely depend on the interplay between task demands, learner characteristics (e.g., working-memory capacity, acquired strategies for self-regulating GBL), and different cognitive and motivational processes triggered by emotion. Positive activating emotions likely enhance learning under most conditions. Accordingly, our meta-analysis revealed significant positive relations of enjoyment and curiosity with achievement across diverse technology-based environments, including GBLEs (Loderer et al., 2018). In contrast, negative deactivating emotions, such as boredom, are generally detrimental to learning (Tze, Daniels, & Klassen, 2016).

Achievement effects of positive deactivating and negative activating emotions are more difficult to predict. Positive deactivating emotions may reduce task attention and strategic efforts but increase long-term motivation to learn. It is an open question whether the interplay of these mechanisms facilitates or reduces overall achievement. Negative activating emotions produce task-irrelevant thinking and undermine intrinsic motivation to learn but can promote extrinsic motivation and facilitate rehearsal of contents, which can be conducive to specific GBLE tasks, such as rule memorization. However, the modal impact of these emotions on cognitive outcomes is likely to be negative (Goetz & Hall, 2013).

In sum, emotions are important drivers and not mere by-products of learning. However, simply equating pleasant emotions with positive effects, and unpleasant emotions with negative effects, on learning does not adequately capture the complex ways in which emotions can impact GBL.

Theoretical Corollaries

Feedback loops between emotions, their antecedents, and their outcomes Our model proposes that emotions, their antecedents, and their outcomes are linked by reciprocal causation (arrows 12–17 in figure 5.3; see also Pekrun, 2006). GBLEs and learner characteristics shape emotions through individual appraisals and emotional transmission, and these emotions in turn impact learning. However, emotions can also feed back into learners' appraisals. For instance, being curious about game contents can grow appraisals of intrinsic value of these contents. Furthermore, learning activities and their outcomes reciprocally influence emotions and their antecedents (Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017). Success and failure at learning are critical sources of learners' competence beliefs and the emotions driven by these beliefs.

In classroom contexts, learners' expressed emotions and achievements can shape the reactions of teachers or peers, including emotional responses (e.g., pity) as well as instrumental behavior (e.g., design of appropriate learning tasks). Similarly, during GBL, players' emotions may be reciprocated by emotionally expressive virtual or human instructors or peers. Affect-aware GBLEs offer remediation to combat ineffective learning or uphold adaptive emotions based on real-time diagnosis of learners' cognitive, motivational, or emotional states (Calvo & D'Mello, 2012). Thus, learners' emotions may reciprocally influence the concurrent configuration of GBLEs, which, in turn, shapes their subsequent emotional trajectories (arrows 18–23 in figure 5.3).

Contextual specificity versus relative universality of emotions during learning We extend insights from general emotion research to GBLEs because functional mechanisms of emotions, including their linkages with appraisal antecedents and learning outcomes, are thought to be universal across individuals, genders, subject domains, cultures, and different learning environments. Basic functions of emotions are bound to species-specific characteristics of the human psychological apparatus, such that lawful processes in emotional experience are a genuine, universal characteristic of human nature (Pekrun, 2018).

However, as individuals may differ in their appraisals and susceptibility to emotional transmission, they may respond differently to objectively similar events. This property of emotional functioning is also endorsed by the CVT, which emphasizes that incidence rates, intensity, and decay rates of emotions may vary as a function of individual differences, learning environments, and cultures. An important case in point is differences in emotions experienced in GBLEs versus other learning environments. Playful learning is often described as affectively adaptive, which is supported by studies showing that students who learn with a game report more enjoyment than those receiving standard training (e.g., Jackson & McNamara, 2013). This difference is likely linked to different perceptions of the two environments, with the playful variant triggering evaluations that were more favorable.

Studies examining relative universality have demonstrated that levels of emotions can vary across academic domains, genders, settings (e.g., homework vs. classroom learning), and cultures. However, linkages of emotions with control-value appraisals and achievement are largely invariant across these dimensions (see the review in Pekrun, 2018). Similarly, in the meta-analysis by Loderer et al. (2018), relations between emotions and appraisals, as well as learning outcomes, were largely invariant across type of technology-based learning environment, gender, and cultural context. By implication, the cause-and-effect mechanisms of emotions outlined in the previous sections provide a foundational set of guidelines for designing emotionally sound learning environments. Next, we discuss how these can be realized in game-based settings.

Implications for the Emotional Design of GBLEs

Learning games aim to boost learning outcomes by providing platforms for playful and thus enjoyable interaction with contents. These interactions need to be thoughtfully designed to have this effect (Plass et al., 2015). Merely adding game elements, such as reward systems, to tedious activities or poorly constructed tasks results in environments often described as “chocolate-covered broccoli” (Laurel, 2001) that actually give rise to frustration or boredom. Whereas research on the impact of GBLE design on learner emotions is still sparse, meta-analyses show that differences between motivation during learning games and motivation during nongame instruction are generally small but positive (Clark, Tanner-Smith, & Killingsworth, 2016: $\overline{g} = 0.35$; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013: $\overline{d} = 0.26$).

Learners vary in their beliefs, design preferences, and prior knowledge, predisposing them to different emotional reactions. Learning also involves natural phases of joy, anxiety, confusion, or frustration, especially during complex learning. However, research indicates that applying principles of emotional design can enhance learning for all individuals (Plass & Kaplan, 2016). In this section, we discuss how GBLE design may influence learners' emotions (arrows 9–11 and 18–23 in figure 5.3) and deduce general principles for game design from an emotion perspective. Following the approach in Plass et al. (2015), we will describe the effects of visual aesthetic design, musical score, game mechanics, narrative, and incentive systems.

Visual Aesthetic Design

One of the first features learners notice about an educational game is its "look." According to Egenfeldt-Nielsen, Smith, and Tosca (2008, p. 129), visuals "add to the atmosphere, provide a sense of realism, and generally make the world seem alive." In our meta-analysis, learners' curiosity differed across aesthetic designs of learning environments (Loderer et al., 2018). While visual GBLE design may appear as a superficial quality, learners may disengage or even choose not to play a particular game if its overall look and feel is unappealing (McNamara et al., 2010).

Basic emotion-relevant features of visual design include shape and color. Color influences mood. Wolfson and Case (2000) provide evidence that warm red coloring elicits greater feelings of arousal than cool blue coloring. Um et al. (2012) found that infusing multimedia learning environments with bright and saturated warm colors (yellow, pink, and orange) increased learners' positive emotions and enhanced their comprehension as well as knowledge transfer compared to a neutral environment using grayscale colors, a finding that has been replicated by Mayer and Estrella (2014). However, other findings suggest that the color red may signal "danger" or, in achievement contexts, "failure" (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007; Gil & Le Bigot, 2016), thus prompting negative emotions, whereas green colors can evoke positive associations of hope, growth, and success (Lichtenfeld, Elliot, Maier, & Pekrun, 2012). Moreover, children tend to connect bright colors with positive emotions and dark colors with negative ones (Boyatzis & Varghese, 1994). However, there may be cultural and individual differences in color preference (Taylor, Clifford, & Franklin, 2013) such that it may be useful to adapt color schemes to personal tastes. This can be extended to other visual design elements—enabling learners to modify design aspects such as icons may enhance enjoyment of learning by increasing perceived control and intrinsic value through player autonomy (Cordova & Lepper, 1996).

Shape design can also influence learners' emotions. Plass et al. (2014) showed that round, facelike shapes in a multimedia learning environment induced positive emotions. This may be because round shapes resemble human physiognomy and babylike qualities connoted with positive attributes such as innocence, safety, and honesty (baby-face bias; see Plass & Kaplan, 2016). Shape and color may also serve to highlight contrast and guide attention to increase positive emotions and reduce negative ones by helping learners experience mastery and personal control. This also applies to higher-order visual effects, such as learning from dynamic simulations of scientific phenomena (Plass, Homer, & Hayward, 2009).

In a similar vein, the visual appearance of agents that are used in some environments may modulate learners' emotions. This can be done simply by adhering to general rules of aesthetics but also by manipulating the perceived similarity between learners and the agent (Domagk, 2010). Physical attractiveness as well as realistic, lifelike design and motion can positively impact learners' affective responses to virtual characters (Shiban et al., 2015). Agents that resemble the learner in age, gender, and expertise (i.e., peer vs. expert agents) are more positively evaluated by learners and more effective at increasing positive emotions (Arroyo et al., 2013; Baylor, 2011). In GBLEs that permit learners to create *virtual selves* (i.e., avatars), the ability to customize these avatars positively affects players' identification with them (Turkay & Kinzer, 2014), and fidelity in visual representation likely influences the general intensity of learners' emotional involvement in the game (Yee & Bailenson, 2007). For games based on fantasy worlds or fictional realms, however, agent realism may be less helpful emotionally.

Musical Score

GBLEs often rely on sound and music to enliven their narrative. Auditory stimuli can increase learners' enjoyment by extending the sensory experience. In addition, music may directly influence emotions via rhythmic entrainment or associations to real-world events induced by emotional tone. The addition of audible feedback may increase the perceived pleasantness of gameplay, irrespective of specific audio characteristics (Nacke, Grimshaw, & Lindley, 2010). By exposing participants to several variants of a Mozart sonata, Husain, Thompson, and Schellenberg (2002) found that a higher musical tempo increased perceived arousal, whereas mode (major vs. minor) impacted emotional valence. Enjoyment ratings and subsequent performance on a spatial abilities task were highest for the fast-major rendition, confirming that positive activating states are particularly conducive to cognitive performance.

A closely related design feature is the vocal sound of nonplayer characters. Baylor contends that "research conclusively indicates that having a human (as opposed to a computer-generated) voice is preferable to enhance social presence" and that for the design of nonplayer characters "a human voice can lead to increased interest" (Baylor, 2011, p. 295) since it is perceived as more appealing. According to Nass and Brave (2005), important features to attend to in terms of implementing authentic and pleasant voices concern (1) volume, (2) pitch and prosody, and (3) rate of speech. In addition, vocal sounds may infect learners via emotional contagion. For example, an agent voicing excitement over embarking on an in-game quest may entice learners to join in this positive emotional activation.

Acoustic characteristics of GBLEs may also influence their effectiveness in guiding attention to important contents and emotional events within the game, such as an approaching enemy (Collins, 2009; Pawar, Hovey, & Plass, 2017). Explanations that must be integrated with information presented visually (e.g., diagrams) typically lead to better retention if presented in auditory rather than visual mode, particularly in cases where both sources of information are essential for understanding and are thus complementary (e.g., Fiorella, Vogel-Walcutt, & Schatz, 2012). Sound can also be used to give feedback on task performance and make learners aware of mistakes. Such sound feedback can be used to downplay failure or add a celebratory note to success, thus inducing positive emotions.

Game Mechanics

Game mechanics refers to the sets of rules and activities afforded to the learner throughout the game (Ke, 2016; Plass et al., 2015). Key dimensions include the overall match between overt game mechanics and underlying learning goals (e.g., skills to be practiced), task clarity, task demands, scaffolding, and social interaction. These task qualities can strongly affect both actual mastery and perceived competence, and thus learners' emotions during gameplay.

Game mechanics and learning content A well-developed game for learning should include targeted learning mechanics that were informed by learning theory and that are instantiated as corresponding game mechanics (e.g., calculating angles within the framework of building an in-game character's house; Plass et al., 2012). Designers of learning games need to develop activities that provide learners with opportunities to engage effectively with learning materials. Mismatches between targeted learning outcomes and actual learner activities afforded by the game mechanic limit cognitive effectiveness and run the risk of reducing self-efficacy and prompting negative emotions such as frustration.

Task clarity and demands Comprehension can be enhanced by considering known constraints (e.g., limited working-memory capacity) and reducing extraneous cognitive load to facilitate information processing (Plass et al., 2009). As ease of comprehension translates to higher self-efficacy, enhancing clarity should be emotionally beneficial. Game designers may, for example, represent key information through iconic rather than symbolic information, which requires higher mental effort (Plass et al., 2009).

The relative difficulties of tasks can also influence perceived control over learning, and the match between task demands and competencies can influence learners' valuation of the learning game, further affecting their emotions. Demands that are either too high or too low may reduce the intrinsic value of tasks to the extent that boredom is aroused (Pekrun, 2006). However, there may be circumstances where cognitive impasses induced by high demands can increase learning gains. D'Mello, Lehman, Pekrun, and Graesser (2014) used a modified version of *OperationARIES!* to induce confusion through staged disagreements between virtual agents when training scientific reasoning, which led to increased retention and knowledge transfer. Confusion can be elicited through provision of unexpected, counterfactual, or contradictory information, false feedback, and tasks that exceed learners' current skills. However, to be productive, confusion needs to lead to resolution activities, which requires that the learner have the capability to resolve the confusion and that the GBLE provide appropriate scaffolds when needed (D'Mello, Blanchard, Baker, Ocumpaugh, & Brawner, 2014, p. 41).

Scaffolding Cognitive scaffolding includes adjusting the task difficulty, repeating content, providing supplemental explanations, using advance organizers to structure information and facilitate navigation in the game space, and supportive messages by game characters (Arroyo, Muldner, Burleson, & Woolf, 2014). Metacognitive scaffolding guides learners toward effective problem solving (e.g., providing hints, rephrasing problem statements), modifies ineffective strategies (e.g., "Let's think again: What are the steps we have to carry out to solve this one?" Arroyo et al., 2014, p. 82), and prompts goal setting and self-monitoring. The meta-analysis by Loderer et al. (2018) found that scaffolding resulted in higher levels of enjoyment, likely due to positive effects on perceived control over learning.

However, the dosage of such interventions may modulate their impact on mastery perceptions. Frequent reminders or calls to change one's learning approach may hinder rather than promote self-regulation and result in a loss of perceived autonomy and control. Therefore, intelligent games that infer learners' cognitive states, account for individual differences in prior knowledge as well as learning pace, and "interfere" only where necessary may be most effective (Janning, Schatten, & Schmidt-Thieme, 2016). Promising developments also include algorithms that allow learner-controlled problem selection in gamified intelligent tutoring systems, including open learner models (e.g., visualizations of a system's learning analytics that reveal learning progress; see Long & Aleven, 2017) or provision of customized cues (e.g., "That was too easy for you. Next time, go for a more challenging problem—it's much more exciting and it will help you increase your learning!" Arroyo et al., 2014, p. 81). Such scaffolds may help avert loss of control when students are overwhelmed by too much autonomy (e.g., because of poor planning and monitoring capabilities).

Social interaction Games can involve social interaction with fellow players or virtual agents. Social interaction can influence learners' emotions in two ways. First, interlocutors may influence one another via emotional contagion and empathy. This makes it possible to regulate learners' emotions through modeling (e.g., enthusiastic expression and exclamations such as "This looks like fun!"), parallel empathy (i.e., replicating the learner's state), and reactive empathy (i.e., displaying emotions that differ from the learner's state in order to alter it). The features of agent design described earlier may be important moderators of the effectiveness of such interventions. For instance, realistic agents might provide more convincing role models and thus more powerful interventions.

Second, opportunities for social exchange may fulfill students' needs for relatedness, thus making the game more enjoyable (Sheldon & Filak, 2008). However, social contact per se may not suffice in building positive emotion: the perceived quality of interaction is key (Heidig & Clarebout, 2011). Supportive, empathy-driven interaction may be most beneficial. For instance, polite "face-saving" measures such as delivering hints using collective formulations (e.g., "How about we solve for x?") instead of directives (e.g., "You need to solve for x"; Lane, 2016, p. 51) can positively impact learners' affective responses.

In addition, the cooperative or competitive structure of interaction can influence students' emotions by impacting their goals during learning. While both cooperative and competitive formats may increase situational interest and enjoyment relative to individual modes of play, cooperation seems to be most effective (Ke & Grabowski, 2007), except for the acquisition of procedural skills, where collaborating and negotiating with others may reduce performance and competition and individual learning may be more efficient (Plass et al., 2013). Competition can prompt performance-avoidance goals (Murayama & Elliot, 2012), which shift learners' focus toward possible failure and lack of control, thus making negative emotions more likely. Moreover, competitive goal structures imply that some individuals have to experience failure and are thus "predestined" to experience negative emotions. As such, cooperative game formats, perhaps interspersed with appropriately scaffolded competitive activities, may be most conducive to encouraging learners' positive emotions.

Narrative

Well-constructed narratives are gripping because they entail a delicate balance of adhering to common episodic schemas creating expectations about upcoming events while at the same time building suspense that sustains attention (McNamara et al., 2010). Narrative can increase enjoyment during GBL (Cordova & Lepper, 1996). Effective games include compelling story lines that contextualize learning and provide an overarching framework connecting rules of play, in-game character roles, events, and incentives.

The success of a game's story line may derive from its alignment with the knowledge or skills to be taught. Such alignment is essential to the meaningfulness of narrative (Ke, 2016). However, meta-analytic findings suggest that games using irrelevant or little-developed story lines produce higher learning outcomes than games with a highly relevant and developed plot, suggesting that "some thin narratives are incredibly engaging, whereas some thick narratives may be dull" (Clark et al., 2016, p. 113) or too complex for students to follow. Thus, a narrative's accessibility and genuine entertainment value (e.g., creation of suspense, inclusion of humoristic elements) may be more critical for sparking curiosity and enjoyment. Creating credible agent personalities involves decisions about communication styles (i.e., formal vs. colloquial), which should vary with agents' specific functional roles (e.g., expert vs. peer agent or protagonist vs. antagonist; see Johnson & Lester, 2016).

Games allow nonlinear narrative structures that enable learners to see their actions impacting the game environment, which can increase perceived control. Narrative may be most engaging when it does not simply serve to advance the story but when the interplay of narrative and player choices actually constructs the story (Dickey, 2015). Student-centered narrative design that involves learners in story creation may enhance valuation of the game as well as perceived autonomy and control (Whitton & Hollins, 2016). To the degree that plot development is contingent on successful task completion, it also allows providing feedback without overtly emphasizing failure, thus dampening potentially harmful effects of making mistakes on learners' perceptions of competence.

Incentive System and Feedback

Learning games include specific incentives (i.e., reward and punishment) that seek to keep learners motivated. Incentive systems include progress bars, point score systems, badges, opportunities to change the environment (e.g., appearance of one's avatar), or access to game levels and virtual goods. Incentives impact learners' perceptions of the value of activities. Because they are typically contingent on learners' in-game performance, they also comprise feedback about individuals' learning progress that influences their perceived control.

The instrumental value of incentives within the game can vary. Rewards that entail access to additional fun activities or unlock new levels with new content focus on building value through inherently valuable content. Such incentives may be particularly conducive to increasing enjoyment or curiosity by boosting interest (McNamara et al., 2010). Extrinsic incentives include rewards that allow learners to trade earned points for their choice of avatar design or color scheme, or tallying scores for comparison with other players through leaderboards. Such incentive systems can enhance the value of learning through external compensation. They may provide an important means for emotionally engaging learners who perceive the content as having little appeal and can serve as a means to build interest value.

Incentives can also differ in their emphasis on specific goal orientations. Different standards for defining achievement can imply individualistic (mastery), cooperative, or competitive (normative) goal structures. These structures can be communicated through rules for awarding points (e.g., for individual improvement vs. outperforming other players) and by feedback messages (e.g., referencing improvement in correct solutions vs. how one performed in relation to others). Incentives and feedback reflecting mastery- or performance-approach goals can facilitate positive emotions (Pekrun, Cusack, Murayama, Elliot, & Thomas, 2014). Mastery standards and mastery-approach goals are held to be most adaptive, because they may lead learners to focus on the intrinsic values of game activities. Normative standards and performance-approach goals may nonetheless challenge and excite learners to engage with the learning game.

Evidence collected by Plass and colleagues (see Biles & Plass, 2016) suggests that administering badges focused on social comparison (e.g., "You figured out the straight angle rule faster than most players!") can lead to higher learning outcomes than mastery badges (e.g., "You have mastered the triangle rule!"). In the mastery condition, learners reporting high situational interest in the game's contents performed better than those with low situational interest. Situational interest did not affect performance in the performance badge and no badge conditions. These findings point to interactions between goal-priming incentives and interest, but more research is needed to clarify these relations.

Mastery-oriented feedback can be augmented with control-enhancing statements derived from attributional retraining (Perry, Chipperfield, Hladkyj, Pekrun, & Hamm, 2014). Arroyo et al. (2014) showed that focusing agent-delivered feedback on the controllability of learning and the importance of effort (e.g., "Good job! See how taking your time to work through these questions can make you get the right answer?" Arroyo et al. 2014, p. 81) can reduce negative emotions such as frustration and anxiety. Such messages seek to regulate learners' emotions by prompting adaptive control appraisals. To reduce boredom, feedback can focus on appraisals of the utility value of learning contents (see Harackiewicz & Priniski, 2018).

Two additional factors are learner choice and salience of rewards. A choice between different rewards can increase perceived autonomy and control over learning but may come at the cost of learners becoming sidetracked by peripheral elements such as avatar modification (McNamara et al., 2010). For salience, visually elaborate or acoustically supported presentation of extrinsic rewards can enhance their emotional pull but may undermine intrinsic valuation of the learning game—a critical effect, especially if rewards are presented frequently (Abramovich, Schunn, & Higashi, 2013). Constantly flagging badges can overemphasize the value of achievement at the cost of the game's playfulness, which can be particularly detrimental to learners who struggle and experience failure. Formulating feedback and awarding incentives based on individual learner progress rather than raw achievement, as outlined by Arroyo et al. (2014), may help alleviate this issue.

In sum, crafting emotionally effective learning games requires a host of decisions at different levels of game design. Design strategies map onto different phases of the emotion process. They can target appraisal antecedents of learners' emotions through appropriate construction of game mechanics and tasks, narrative structures, visual and sound elements, and incentive structures, as well as the emotion itself through design features that enable emotional contagion or empathy.

Open Questions and Directions for Future Research

Emotions are powerful drivers of learning across all types of learning environments. However, compared with the number of studies focusing on cognitive aspects of learning games and game design, emotion research is lagging behind. We outline five major directions for future research on emotions in GBL. These areas echo questions that concern the field of educational emotion research as a whole, which suggests that collaborative efforts are needed to advance this field (Pekrun & Linnenbrink-Garcia, 2014b; Plass & Kaplan, 2016).

Clarifying the Construct Domain of Emotions

Future work needs to address boundaries between domains distinguishing emotion from adjacent categories, as well as the internal structures of these domains. There is general consensus that emotions such as joy, anger, or anxiety are core members of the domain of emotions, but there are other constructs for which this is unclear, such as metacognitive feelings. For internal structures, it remains unclear whether dimensional or discrete emotion approaches are better suited for describing a learner's affect. For game design, this makes a crucial difference in terms of the emotional granularity considered. D'Mello, Blanchard, Baker, Ocumpaugh, and Brawner (2014) argue that discrete representations are preferable to dimensional ones when devising affect-sensitive instructional strategies, because emotions of the same dimensional category (e.g., negative activating anxiety vs. anger) can have different antecedents that require different regulation strategies. In addition, parameters of emotions (e.g., intensity, expressive behavior) can vary between individuals and cultures, implying that any approach to emotion definition and emotional design needs to be validated across different groups of learners.

Dynamic and Multimodal Measurement of Emotions

Educational researchers and computer scientists have made significant headway toward implementing online assessment of emotion by considering different "channels," such as physiology, facial expression, and subjective feeling, and examining how technology inherent to the learning environment can be used to measure emotions in more holistic ways (D'Mello, Dieterle, & Duckworth, 2017). While the accuracy of these methods leaves room for improvement, this direction is promising. First, automated multichannel methods consider the multicomponent nature of emotions. Supplementing self-report with measurement of facial expressions or physiological processes may improve measurement validity, as not all emotion components are consciously accessible. Second, such approaches take the dynamic nature of emotion into account, providing a richer analysis of fluctuations in learners' emotions through continuous real-time assessment. This is of central importance for developing emotion-sensitive games. Automated methods also afford continuous assessment of emotion without interrupting the natural flow of learning and circumvent response biases such as social desirability.

Evaluating the Emotional Design of GBLEs

Researchers have begun to consider how learning environments, both classroom and technology based, can be shaped in emotionally sound ways (Lester et al., 2014; Plass & Kaplan, 2016). However, there is a need for a more systematic, rigorous evaluation of the impact of design features of learning games on emotions conducive to learning. Emotional effects of design choices need to be examined more closely at all levels of game design (i.e., visual and sound design, game mechanics, narrative, and incentive structures; see figure 5.3). In doing so, possible transitions and influences between different emotions should be examined. For example, GBLEs hold great potential for inducing positive aesthetic emotions, so it would be useful to know whether these emotions also foster learners' intrinsic valuation of learning and learning-directed emotions. Answers to such questions may also settle the ongoing debate on the seductive detail effect (Park, Flowerday, & Brünken, 2015) by shedding light on whether emotions triggered by decorative GBLE elements can promote enjoyment *of learning*, motivation to invest effort, and ultimately learning outcomes.

Considering Inter- and Intraindividual Factors in the Emotional Design of GBLEs

The majority of studies in educational psychology have relied on between-person analyses, and emotion research is no exception. Whereas analyses based on covariation between persons are well suited for investigating individual differences, they do not contribute to our understanding of the variation that occurs within an individual across time, nor do they adequately address predictive or cause-and-effect relations between variables within individuals (Murayama et al., 2017).

Considering variation of emotions and their antecedents both between and within persons is particularly relevant for developing intelligent games that offer tailored learning environments. Design research needs to evaluate how the emotional impact of game features may vary for learners who differ in age, gender, cultural background, goal orientations, or prior knowledge, and how emotional impact may differ and evolve within individuals as they progress through the game. For example, prior knowledge likely varies between learners at baseline, implying that different degrees of task difficulty and scaffolding are required to maintain optimal levels of challenge. As learners gain knowledge through completing in-game activities, they may benefit—both cognitively and emotionally—from more autonomy. Therefore, an important avenue for future work is to develop games that are able to shift power from system-controlled personalization (adaptivity) to learner-based customization (adaptability) as learners become more skilled.

Building Integrative Theoretical Frameworks

It is tempting to assume that capturing emotional processes will require different theoretical models for different types of learning environments. Given that these processes are fundamental to the nature of learning, extant theories should be just as relevant to GBL as they are to formats that are more traditional (Plass et al., 2015). However, researchers and game designers are faced with the issue of selecting from an unwieldy array of different constructs and theories in this field. As many existing theoretical models are complementary rather than mutually exclusive, integration is needed to move the field forward. Theoretical integration is especially needed to promote cross-fertilization across disciplines that to date have worked in relative theoretical and empirical isolation, such as inquiry on emotion in educational psychology versus affective computing. We hope that the integrative model of emotional foundations of GBLEs presented in this chapter is an initial, useful step in this direction.

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6 Motivational Foundations of Game-Based Learning

Richard M. Ryan and C. Scott Rigby

Introduction: Motivation as a Core Element in Game-Based Learning

Game-based learning and gamification in education are hot topics and engender the core focus of this handbook. Whether using games to enhance learning or directly integrating game mechanics into learning experiences (gamification), the intent of these approaches is to motivate learners by using game elements to enhance their interest and engagement in something important or serious. People in educational and organizational settings of all varieties are turning to these approaches to enhance their training, teaching, marketing, and survey efforts. Everywhere, we see the effects of this movement popping up in the features, graphic styles, feedback systems, and contents of our devices, media, and e-learning tools.

But why this clamoring for using games? The answer is clear. Business organizations and educational institutions alike increasingly recognize that among the most valuable and yet hard-to-garner resources is people's attention. There is so much competition for it in the modern world. Yet, within this competitive environment, games—most notably video games—have emerged as examples of success not only in capturing people's attention but also in holding it, often fostering long-term loyalties. This has made video games role models for engaging learners and consumers (Rigby, 2014). Therefore, the hope is that through game approaches and making tasks more fun, employees, students, and consumers can be induced to persist at activities long enough for important information, practices, or skills to be assimilated. The use of games and gamification is therefore most essentially a *motivational intervention*—a strategy to facilitate sustained engagement.

A secondary hope is that because games can sometimes produce a high *quality of engagement*, in which there is intense personal involvement and concentration, gamification might lead to deeper processing of information and thus more effective learning. Indeed, successful video games often involve highly interactive, choice-driven, and competence-satisfying features, leading to the belief that gamification can enhance not only persistence but also the efficacy of teaching or training efforts. Gamification thus also represents a strategy for *learning enhancement*.

Unfortunately, many efforts to use games fail at both these goals (van Roy & Zamen, 2017). Integrating games into the learning process, or *gamifying* learning through game mechanics, does not magically enhance either engagement or cognitive outcomes. In fact, game features can often unwittingly do exactly the opposite, inclining people to *game the games* by finding shortcuts or giving answers they think are desired or being reinforced. Some strategies also leave people feeling manipulated, controlled, or distracted from the meaningful learning and development of interests that the games are intended to promote.

Simply put, games—even those designed purely for entertainment—are not invariably engaging, nor do their mechanics guarantee more successful learning experiences. Success at these goals requires more than simply injecting game dynamics into learning and work tasks. As the rich empirical literature on intrinsic motivation and autonomous engagement has shown, factors such as rewards, social comparisons, competitive structures, and incentives—all of which are frequent elements in game-based learning and gamification—can either enhance or undermine intrinsic motivation and learning outcomes, depending on how they are introduced and on what they are made contingent (Deci, Koestner, & Ryan, 1999; Ryan & Deci, 2017). Yet, many efforts at gamification are not informed by this empirical literature, despite the fact that these established motivational principles have not only been well validated in work and learning contexts (e.g., Deci & Ryan, 2014; Ryan & Deci, 2016) but have also been strongly reconfirmed in video game and media contexts (e.g., Deterding, 2015; Przybylski, Ryan, & Rigby, 2009; Rigby, 2014; Tamborini, Bowman, Eden, Grizzard, & Organ, 2010).

In this chapter, we present an empirically grounded motivational foundation for determining whether games and game mechanics are likely to result in deeper engagement and learning outcomes that are more positive. Within this framework, we examine the key motivational factors that determine successful game experiences as well as the optimal environments for learning, training, and behavior change more generally. Indeed, motivational principles at the heart of effective game approaches are important not only to learning outcomes but also to meaningful engagement with many of the tools used in training and educational programs, such as surveys and aptitude assessments. In our view, optimally engaging individuals to embrace learning activities and goals requires understanding both *how* and *why* specific designs and features of games affect the learner's intrinsic motivation and volition, and subsequently how these design features and experiences can be deployed to enhance learning. Doing so means understanding the psychological satisfactions of competence, autonomy, and relatedness that successful games tap into, satisfactions that are the driving force of high-quality engagement and motivation.

We begin by highlighting the importance of volitional motivation for learning and sustained engagement more generally. A rich body of research in *self-determination theory* (SDT) (Ryan & Deci, 2000b, 2017) has verified the significant role of intrinsic motivation and autonomy in learning and work outcomes, as well as the practical factors in schools and organizations that can undermine these forms of self-motivation. This work has provided principles for how features such as rewards, choices, types of competence feedback, competition, and other elements often salient in gamification functionally impact intrinsically motivated persistence and the experience of interest and enjoyment that typically accompanies it (Ryan & Deci, 2013, 2016).

Even more relevant to this chapter on games and learning is the extension of these SDT formulations into research on video games (Rigby & Ryan, 2011), technology design (e.g., Calvo & Peters, 2014), and e-learning (e.g., Sørebø, Halvari, Gulli, & Kristiansen, 2009). Although game-based learning is not limited to interactive games, video games do represent the most dominant contemporary form of games and game learning initiatives. Indeed, our interest in game-based learning and gamification arose out of systematic research within SDT on the motivating properties of video games. Beginning with Ryan, Rigby, and Przybylski (2006), there have been a number of studies using the Player Experience of Need Satisfaction (PENS) model, which predicts how features of games either effectively evoke or undermine psychological satisfactions for autonomy, competence, and relatedness, and thus impact players' intrinsic motivation, enjoyment, and sustained engagement (e.g., Przybylski, Deci, Rigby, & Ryan, 2014; Rigby, 2014; Rigby & Ryan, 2011).

After presenting the PENS model as it applies to video games and technology use, we then further discuss the application of these ideas in the game-based learning space. In particular, we look at how gamification strategies succeed or fail as a function of their impact on psychological need satisfactions, or the internal rewards so critical to volitional engagement in an attention-demanding world.

Self-Determination Theory: Intrinsic Motivation and Autonomy in Learning

Intrinsic motivation refers to doing an activity for interest or enjoyment (Ryan & Deci, 2000a). Thus, it is defined by an experience of the activity as inherently rewarding and is observable in people's behavioral persistence even in the absence of external rewards (Deci et al., 1999). Being intrinsically motivated is an evolved propensity to take interest in and assimilate one's surroundings and exercise one's capacities. Indeed, the concept first emerged in research on the exploratory tendencies and curiosity of primates and was later extended to work with humans (see Deci & Ryan, 1985). Intrinsic motivation is not only a driver of play and interest-driven exploration but also underlies the preponderance of learning in early human development more generally (Ryan & Deci, 2013). Even after childhood, in settings such as classrooms or organizations, much significant learning continues to occur through intrinsically motivated curiosity and interest. Research suggests that intrinsic motivation is associated with both significant activations of the dopaminergic pathways in the human brain associated with pleasure and greater sensitivity to feedback, both positive and error related (Di Domenico & Ryan, 2017; Miura, Tanabe, Sasaki, Harada, & Sadato, 2017). In contrast, external rewards can actually undermine intrinsic motivation and the striatal and midbrain activations associated with it (e.g., Reeve & Lee, 2019), mainly by diminishing the sense of autonomy in activity engagement, which is an essential element in intrinsic motivation (Deci et al., 1999; Ryan & Deci, 2017). Such research builds on decades of behavioral evidence concerning why and how intrinsic motivation is predictive of enhanced engagement, as well as learning and performance in many settings.

Although there are multiple manifestations of intrinsic motivation, it seems clear that the experiences, skills, and knowledge acquired through playful engagement with one's environment have functional value for adaptation and development. Because intrinsic motivation is catalyzed by opportunities for interactive, self-driven activity, it also tends to lead to deeper processing of material and to learning experiences that are better maintained and transferred (e.g., Grolnick & Ryan, 1987; Yamauchi & Tanaka, 1998). Similarly, within organizations, intrinsic motivation, and autonomous forms of motivation more generally, have been central variables in explaining job satisfaction, performance, and organizational citizenship, among other variables (e.g., Clayton, 2014; Deci, Olafsen, & Ryan, 2017; Fernet, Austin, & Vallerand, 2012; Guntert, 2015).

As mentioned, the aim of game-based learning is to foster the kind of engagement that involves active and motivated assimilation and greater integration of knowledge. In this regard, both field studies and meta-analytic reviews point to intrinsic motivation as perhaps the most important type of motivation in fostering school achievement. For example, Taylor et al. (2014) examined specific types of motivation and academic achievement. Their meta-analysis of cross-sectional studies highlighted a significant role for intrinsic motivation in predicting achievement. They presented three additional empirical studies of high school and college students in Canada and Sweden that implicated intrinsic motivation as the type of motivation most consistently associated with achievement gains. Similarly, focusing on ethnically and racially diverse students, Froiland and Worrell (2016) reported that intrinsic motivation predicted school engagement, which in turn predicted higher achievement. In contrast, when intrinsic motivation for learning is low, both learning outcomes and student wellness are in jeopardy, as longitudinal data confirm (e.g., Gottfried, Gottfried, Morris, & Cook, 2008). A large body of research has thus well demonstrated the positive learning and experiential outcomes stemming from intrinsic motivation (Ryan & Deci, 2016).

Self-determination theory (Ryan & Deci, 2000b, 2017) represents the most prominent contemporary theoretical and empirical approach to understanding intrinsic motivation. Whereas past behavioral approaches focused on motivation and learning as primarily a function of external rewards and punishments, in SDT intrinsic motivation is posited as being a function of inherent satisfactions associated with people's basic psychological needs (Ryan & Deci, 2000b, 2017). The theory specifically focuses on three basic psychological satisfactions that spark and support intrinsic motivation.

First is the experience of *competence* satisfactions, or feelings of mastery or effectiveness at tasks. Intrinsic motivation is enhanced by a setting rich in effectance-relevant feedback, especially feedback that is immediate and informational rather than evaluative or pressuring. Furthermore, activities that provide barely manageable challenges, clear proximal goals, and immediate feedback enhance intrinsic motivation, results mediated by the satisfaction of competence needs (Ryan & Deci, 2017; Nakamura & Csikszentmihalyi, 2014). Although some other theories, such as social cognitive approaches, similarly emphasize efficacy expectations (e.g., Bandura, 1989, in SDT, competence or efficacy alone is not sufficient. Efficacy must be accompanied by a sense of *autonomy*—the opportunity to feel volitional and self-regulating in one's actions. Intrinsic motivation is undermined when autonomy is thwarted, such as through perceived pressure, external control, or micromanagement of the person. Finally, in many contexts, intrinsic motivation can be enhanced by satisfactions of *relatedness*, or feeling connected and significant to others. Relatedness is especially effective at enhancing intrinsic motivation when people are able to cooperate in tasks, help each other, or pursue common goals, rather than compete or engage in social comparisons.

Both the experimental and applied literature of SDT demonstrate how specific factors affecting these three psychological needs for competence, autonomy, and relatedness directly predict intrinsic motivation, as well as the outcomes of high-quality motivation such as learning and the maintenance and transfer of knowledge. Experimental studies have specifically detailed how various external events, such as rewards contingencies, time pressures, feedback styles, competitive structures, and other factors, impact intrinsic motivation in ways mediated by these satisfactions. Their results are often surprising. For example, although many people expect, and indeed feel wrongly certain (see Murayama, Kitagami, Tanaka, & Raw, 2016), that external rewards will invariably enhance intrinsic motivation, results show that this is generally not the case (Deci et al., 1999). Externally administered rewards frequently undermine intrinsic motivation rather than enhance it, especially when they are explicitly used to motivate behavior or learning (Ryan & Deci, 2016). In fact, extensive empirical literature shows that when external factors, including rewards, grades, badges, or other incentives, are used in controlling ways, they tend to undermine intrinsic motivation and narrow people's focus and active engagement with materials. Yet, when contexts support autonomy, for example by providing choice, minimizing rewards and evaluations, allowing ownership, or providing a meaningful rationale for acting, intrinsic motivation can be enhanced.

Motivation in Video Games: The PENS Model

As we previously stated, interest in gamification stems from the observation that successful video games are highly motivating and can foster both deep and long-term engagement. Within SDT, we have directly investigated how the engaging properties of games might be explained by how well digital games support competence, autonomy, and relatedness. That is, we have focused on the positive motivational features entailed in highly successful video games, as well as the factors that lead games to fail. Our focus on the powerful motivational properties of video games contrasts with literature primarily focused on the negative consequences and correlates of computer gaming. Whereas some studies on games are concerned with how games might engender problems from violence to obesity, what is often missing is an examination of what is behind the undeniably powerful desire people have to play them.

No doubt, the answer to why people are powerfully drawn to games seems obvious to many: people play video games because they are fun. This answer is unsatisfying because it is neither precise nor practical. We need to understand the mechanisms that make games fun if we are to wittingly apply a motivational framework to the creation of new games and game learning initiatives. Moreover, fun seems an inaccurate explanation for the considerable investment of time, effort, and attention voluntarily invested in game activities that in and of themselves are tedious and repetitive rather than fun; games clearly evoke a set of motivations more complex than simple hedonic pursuit of feeling good (Rigby & Ryan, 2011).

Our initial empirical work applying SDT to games assumed that successful games were highly intrinsically motivating, yielding significant satisfactions of basic needs for autonomy, competence, and relatedness (Ryan, Rigby, & Przybylski, 2006). Four studies involving various types of games demonstrated that both game preferences and behavioral and psychological measures of intrinsic motivation for playing them were predicted by these three basic psychological need satisfactions during play. Simply put, basic need satisfaction was found to be the pathway to both enjoyable and engaging game experiences and to people's motivation to persist at them. Importantly, the findings also further highlighted how specific factors within successful video games facilitated these three need satisfactions. Factors such as having controls that were easily mastered, feedback that was clear and consistent, choices regarding goals and strategies, and opportunities for cooperative social interaction enhanced these need satisfactions, which were in turn predictive of increasing intrinsic motivation and engagement.

An important aspect of this conceptualization is its focus on what makes an experience rewarding. Past research stemming from classic reinforcement perspectives focused primarily on how external rewards and contingencies shape behaviors and condition persistence. The focus of SDT is instead on the *internal rewards* spawned by various types of experiences, and their role in energizing sustained engagement. The fact that these internal rewards associated with autonomy, competence, and relatedness activate the same brain systems (e.g., the striate nucleus) as classic reinforcement systems bespeaks why they can so readily produce persistent behavior even in the absence of externally administered rewards (Reeve & Lee, 2019; Ryan & Di Dominico, 2017).

These findings suggest that an important motivational component of game-based learning is a deep and fundamental integration of learning goals as part of the game systems deployed to reach them. Game mechanics clearly have powerful mechanisms for internal rewards that intrinsically draw players forward into deeper engagement. However, players are also brutally efficient in pursuit of these rewards and optimize their pursuit only of the contents and experiences that afford them. For instance, we have observed how players skip over backstory in quest narratives in games like *World of Warcraft*, because they know the specific tasks are detailed at the end. Even when cleverly presented, the narrative may not be processed as the player cuts to the task demands. If learning material is not in that satisfaction loop, it will not benefit from being loosely juxtaposed near game content. In this circumstance, game content becomes a competitor for attention and engagement rather than a conduit for deeper learning.

An example of this motivational efficiency is readily seen within player experience testing using our Player Experience of Need Satisfaction (PENS) (Rigby & Ryan, 2011) model, which entails measures of autonomy, competence, relatedness, and controllability during gameplay. Game designers wish to promote a certain set of content, and to do so they link engagement with that content with a need-satisfying experience, such as the common game feature of *leveling up*, in which players obtain greater power and opportunity (competence and autonomy satisfactions) as they progress through game challenges. When well executed, the content itself will facilitate the achievement of this higher growth (e.g., a story line that—when engaged—reveals clues that enable more effective growth). However, if there is no explicit or implicit value to the content being put in front of the player, they will simply seek the fastest way around it or through it that allows them to achieve the more need-satisfying experience. More simply put, players need to see a rationale for engaging with learning content within the context of the game's rules for success—something that makes that content the player's ally in achieving satisfaction of basic needs for autonomy, competence, and relatedness. This in turn leads to greater intrinsic interest in the learning experience rather than seeing learning as the toll that is paid in order to have fun in the game.

What is notable in this exploration of the motivational foundations for game-based learning is that we have a common motivational fulcrum on which both deeper learning and deeper engagement with games pivots, namely the satisfaction of basic psychological needs for competence, autonomy, and relatedness (Rigby & Przybylski, 2009). Understanding the core mechanics, content, and experiences in video games that accrue to greater need satisfaction (and greater enjoyment) is therefore highly instructive of the motivational dynamics that underlie successful game-based learning. Thus, in what follows we turn to how these specific internal satisfactions are embedded in successful video games, and factors that facilitate or obstruct these need satisfactions, to exemplify motivational best practices in game-based learning that can be expected to enhance both enjoyment of and learning from game-based approaches.

Basic Need Satisfactions in Video Games: Principles and Examples

Competence satisfactions in video games From the earliest arcade games, such as *Space Invaders* and *Pac-Man*, to contemporary games such as *Minecraft* and *Angry Birds*, perhaps the most pervasive satisfaction built into games is rich competence feedback. Experiences of competence occur when people have opportunities to experience efficacy and success and thus derive feelings of mastery and competence. Nearly every successful video game has strong elements that support feelings of competence. As noted, the experience of leveling up—in which players experience growth and efficacy in their abilities by reaching proximal goals—is a fundamental mechanic that motivates players based on its satisfaction of the need for competence. Important from an SDT standpoint is that these rises in rank are more than just cosmetic; in order to truly satisfy, the advancement must be accompanied by a grant of more capacities (e.g., the ability to wield more power in the game, faster transportation capacities). This advancement, in turn, must have functional meaning to further need satisfaction as well. The newly minted capabilities will be motivating only to the extent they enable success at greater challenges, thereby offering feelings of progress and opportunities for further growth and leveling up. In short, a virtuous cycle is built between the landscape of activities and challenges and the growth (and competence satisfaction) that accrues from engaging in and succeeding at such activities.

Also supporting competence satisfactions is the *clarity of goals* embedded in successful game designs. In successful games, the goals and quests one pursues are quite clear in their structure and expectations. As the player progresses toward the goal, feedback on progress is immediate and frequent, thus providing a dense field of competence-supportive messaging and a sustained feeling of mastery. As specified within SDT, such positive feedback amplifies intrinsic motivation (Ryan & Deci, 2000a; Vallerand, 1997).

Rigby and Ryan (2011) describe how the most successful games typically offer multiple sources and layers of feedback to achieve strong competence feedback and support. During gameplay there is usually ample *granular feedback*—on-screen effects or visible points that instantly appear in response to effective player actions. Complementing this moment-to-moment feedback is *cumulative feedback*, showing one's more general progression through the arc of the game. This cumulative feedback supports players as they pursue more distal goals, providing a sense of purpose and progress and helping to sustain play through more difficult challenges. Cumulative feedback is also accessible in visualizations that in an ongoing way support a sense of growth and competence. Furthermore, in successful designs, players are allowed to choose the level of challenge they undertake moment to moment, supporting their autonomy over the game experience alongside their ability to optimize their experience for greater competence satisfactions.

Autonomy satisfactions in video games Most early digital games primarily emphasized competence satisfaction (e.g., *Tetris*, *Space Invaders*). Although still an emphasis, especially in mobile games (e.g., *Angry Birds*, *Candy Crush*), as the video game industry has developed, more and more features affording autonomy satisfactions have been introduced into game design, resulting in games that are more compelling and engaging. Indeed, the very nature of virtual environments removes constraints and barriers that are often present in the molecular world, affording myriad opportunities for novelty and choice (Rigby & Ryan, 2011). In virtual worlds, one can do almost anything. This exponential expansion of choice opportunities means that games can be a wellspring for autonomy satisfactions. Indeed, in the game-based learning arena, some of the most successful implementations over the last decade have been in the use of successful games such as *Civilization* and *Minecraft*, which our research shows primarily engage through the deep satisfaction of autonomy that comes from being set loose in a virtual world of possibilities and dense goal structures.

Opportunities for choice are salient from the outset in many such video games. Frequently even before play begins, players can *personalize* their play by designing an avatar that reflects them personally, including choice of gender, species, character type, powers, playing style, and developmental trajectory. All these choices facilitate a greater sense of empowerment and autonomy.

Good games also allow players to choose activities from a large menu of options. Choices over proximal goals, strategies, and tools help people feel a sense of personal accomplishment as they advance. Moreover, technology advances have enabled increasingly intricate open-world designs, in which choices over movements, quests, and activities are both enlarged and deepened, creating a true sense that one is free to create a self-narrative characterized by success, growth, and meaningful impact of one's choices on the world one inhabits (Rigby & Przybylski, 2009).

Hugely successful games such as *World of Warcraft*, an open-world multiplayer adventure game, create massive environments to explore, each with unique challenges. Part of the fun of these worlds are these opportunities for exploration and discovery—core elements in our evolved intrinsic motivational propensities (Ryan & Deci, 2017). Another prime illustration of this is the often-demonized *Grand Theft Auto* (GTA) series, in which players can pursue a wide variety of missions and goals, including criminal activities. As described by McCarthy, Curran, and Byron (2005), this game's salient antisocial themes and content have often led reviewers to miss the point as to why it is such a highly successful game. As these authors state: "People don't play it for the violence;

they play it because it affords the opportunity to do whatever they please" (McCarthy, Curran, & Byron, 2005, p. 24). Open-world games are attractive precisely because players can venture in any direction through richly illustrated landscapes, choosing among tasks and missions. Open-world elements thus promote engagement because they afford *opportunities for action*, thereby expanding options and choices, encouraging exploration and manipulation, and accordingly evoking the intrinsic motivational tendencies already deeply embedded in our evolved natures (Ryan & Hawley, 2016). Is it thus little wonder why people love to be engaged in such virtual worlds?

Of particular note is the trend in successful games to provide a matrix of content and game mechanics that enables players to feel they have created a personal narrative that is unique. Despite the open-world genre of games being labeled *sandbox* games, these worlds do not succeed simply by densely scattering content on the ground and dropping players into the middle with no road map. On the contrary, the most successful games today marry opportunities for choice with an elaborate structure: choices have consequences that change both the player and the game world (and the characters within it); goal structures are elaborate and ordered, with proximate and distal goals; and the consequences of choices create detailed and varied experiences for the player in both the game's story and the subsequent opportunities presented. The net result is that players feel the story they are writing as they play is their own, and this story gives them something unique to feel proud of and to share with others, who in turn can share the quite different narrative they are creating, even within the same game world. As we'll see shortly, this is one way in which games—and the social networking that surrounds them—foster relatedness satisfaction alongside competence and autonomy.

With respect to game-based learning, this highly effective game structure parallels findings within SDT research on the classroom conditions that facilitate deeper learning. For example, Vansteenkiste et al. (2010) found that students' autonomy for learning was strongest when teachers supported autonomy (through mechanisms such as meaningful choice) within classroom environments that also had high structure. Patall and Hooper (2017) reviewed evidence on how choice in learning contexts enhances learning, both direct and incidental. Here again, we see the fortunate motivational synergy between learning and game enjoyment. The circumstances and environments that facilitate learning are, happily, also those that deepen enjoyment through autonomy and competence satisfactions, leading to sustained engagement.

Relatedness in video games Relatedness needs are satisfied when a player connects with others in the game in a way that makes the player feel that they matter to those others. Events in which one is supported by others, acknowledged, or able to help others are all experiences that enhance the sense of relatedness (Martela & Ryan, 2016; Weinstein & Ryan, 2010). Although early video games were largely solitary experiences, the most popular games today succeed specifically because they are designed for multiplayer activities that encourage communication, cooperation, team play, and other relatedness-enhancing experiences. These experiences are deepened directly through the game's design, which encourages players to differentiate their roles as they play together in order that each player contributes something meaningful to their teammates and the overall success of the game. One of the most successful genres at the time of this writing is multiplayer online battle arena (MOBA) games that integrate highly competitive team versus team play with rich mechanics for players providing each other support and adopting unique roles and strategies (which simultaneously affords autonomy satisfaction as well through meaningful choice).

Beyond the strong satisfactions through multiplayer design, on a smaller scale, even computer-generated figures or nonplayer characters (NPCs) can afford a sense of relatedness. In numerous research projects commissioned by game developers, we find that players experience relatedness satisfaction from quests that directly involve saving or supporting NPCs and interactions with NPCs who demonstrate that the player's choices are meaningful through dialogue and actions that are contingent on what the player does. For example, NPCs in some current games will applaud the player for specific accomplishments or interactively aid the player in performing a task, engendering feelings of support and gratitude. In some of our studies (see Rigby & Ryan, 2011), we have even found that when a game includes playing with both real people (multiplayer) and NPCs, people will sometimes report even more relatedness to NPCs than to fellow players, especially when those NPCs are more helpful than fellow players, who are not always programmed to be as responsive!

Finally, a strong input to relatedness satisfactions is giving people chances to be helpful or kind to others. According to SDT, in fact, giving people opportunities to contribute enhances need satisfaction. Martela and Ryan (2016) in fact showed in a video game context that adding a feature in which one's performance led to donations to needy people enhanced interest and enjoyment and lowered behavioral measures of postgame depletion.

Experiments increasingly are demonstrating how features of games that enhance the intrinsic satisfactions of competence and autonomy and relatedness are linked to greater enjoyment and engagement. For example, Sheldon and Filak (2008) manipulated autonomy, competence, and relatedness features in a game context, showing that all three factors predicted intrinsic motivation, with competence and relatedness especially affecting positive outcomes such as positive affect and lower negative affect. They suggested that their autonomy manipulation was not particularly meaningful, although it did produce weak effects.

Another excellent example is work by Peng, Lin, Pfeiffer, and Winn (2012). They did research using an *exergame* (an exercise video game) to examine the effects of features associated with autonomy or competence satisfactions. In one set of experimental conditions, they focused on a feature allowing choices about customizing one's avatar, comparing gameplay under conditions in which this feature was turned on or off, manipulations that were expected to impact autonomy. In other conditions, a competence enhancement feature that automatically adjusted difficulty levels based on previous play to create optimal challenges was turned on or off. The manipulation of these features strongly affected a variety of outcomes, including ratings of game enjoyment, motivation for future play, and game preferences. More important for the present discussion, these effects were mediated by autonomy and competence need satisfactions in the expected ways. Personalization and choice options affected autonomy satisfaction, and challenge modulation features affected competence satisfaction, which Peng et al. then showed statistically mediated the relations between conditions and outcomes, as would be predicted by SDT.

The proliferation of social networking technologies has also greatly enhanced how games provide need satisfaction. One of the most successful commercial games of the last decade—*Minecraft*—is also a frequently used title in game-based learning. Interestingly, its success is not simply a result of the need-supportive features within the game but in how social networking has interacted with those features to greatly enhance their potential for need satisfaction. Hundreds of thousands of players share videos of their creations, techniques, and world-creation prowess on social media, which in turn are watched by millions as players seek to grow in their abilities (competence satisfaction), discover new worlds and new opportunities (autonomy satisfaction), and connect with other like-minded players (relatedness satisfaction). In fact, currently the single most-watched content by kids on the popular site YouTube—including television shows and other kid's programming—is *Minecraft* videos (TubularInsights, 2014). Thus, when considering how game-based learning approaches will build and sustain engagement and learning, the social networking environment in which they are situated should be a strong consideration. Game-based learning does not need to reinvent or try to re-create communication and collaboration tools; it simply needs to afford enough need satisfaction to entice players to choose to communicate over the channels students already use every day.

Video Games are Built to Satisfy … Now

Unlike most real-world domains, such as work and school, virtual environments can offer intrinsic need satisfactions with *immediacy*, *consistency*, and *density* (see Rigby & Ryan, 2011). *Immediacy* means that there is little delay in the feedback or outcomes derived from one's choices or actions. *Consistency* means that games can be trusted to reliably deliver feedback and opportunities in ways that are clearly defined within their rule set. Put differently, games can offer a predictable and fair world in which contingencies between actions and outcomes are dependable. Finally, *density* refers to the fact that successful virtual worlds are engineered to yield a very high rate of frequency of need satisfaction, often in contrast to the sparse satisfactions often felt in molecular educational or work contexts.

The immediacy, consistency, and density of satisfactions are in fact a huge part of why games are considered so engaging and intrinsically motivating. It is also part of the motivational promise of game-based learning. Whereas traditional learning often has criteria for success that are more ambiguous and often provides feedback to students that is neither informative for growth nor timely (e.g., simply a numerical grade received two weeks after turning in a paper), game mechanics facilitate immediacy, consistency, and density of need satisfaction in order to more effectively engage and support deeper learning. Indeed, autonomy, competence, and relatedness are internal rewards or satisfactions that yield many adaptive functions, such as spontaneous learning and cooperation.

Our main point is that the strong engagement properties of games—what makes them so compelling—is precisely their ability to deliver basic psychological need satisfactions in reliable, frequent, and rich ways. These elements can be well harnessed by game-based learning and gamification to promote engagement in learning, positive behavioral change, and educational activities.

Immersion and need satisfaction Related to the motivational pull of good games are their immersive qualities. In a good video game, players become so engaged that they temporarily forget they are in a game. In the same way that a reader gripped by a novel enters into the narrative space of events, losing awareness of the outside world, a good video game embeds the player's awareness within its virtual space. Here we drew on Lombard and Ditton (1997), who described presence as an *illusion of nonmediation*, meaning that a person perceives a particular medium as though the medium were not there. Although the concept of presence applies to all forms of media, video games have myriad methods for enhancing it.

PENS points to specific properties of virtual environments that allow people to become transported into an immersive game experience. In the PENS model, we refer to this presence as *immersion*: the sense that one is *within* the game world (Ryan et al., 2006). Specifically, our PENS approach specifies three major dimensions of immersion: *narrative immersion* (one is absorbed in the story), *emotional immersion* (one has appropriate or authentic feelings given the events and context), and *physical immersion* (the virtual world feels compelling as a field for actions) (Rigby and Ryan, 2011; Ryan et al., 2006). PENS analyses suggest that these forms of immersion are not always produced by the usual suspects. For example, game designers often try to produce immersion by making the experience of virtual worlds graphically realistic. This investment in graphic realism, however aesthetically pleasing, is expensive and frequently a challenge for game-based learning initiatives that do not have the resources of a big-budget commercial game. Encouragingly, such graphics are not the strongest predictors that players will become immersed in a game. In PENS-based research, we have found that presence and immersion are less about graphic realism than about a responsive or contingent affordance of need satisfactions (Ryan et al., 2006). It is precisely when basic psychological needs are thwarted that players are apt to break immersion and think about the wires and strings the developer is trying to pull rather than staying engaged with the show on the stage itself. In contrast, if within the game one can readily keep feeling autonomy and competence, then players can really stay immersed in it. In fact, Ryan et al. (2006) showed that presence was enhanced in games that were highly need satisfying, especially those supporting autonomy and competence satisfactions.

Brief summary of PENS The SDT-derived PENS model has much to contribute to an understanding of the motivational power of video games. Clearly, video games, and virtual environments more generally, can be both attractive and lead to persistent play to the degree they are designed to satisfy *psychological needs* for autonomy, competence, and relatedness. PENS is thus a general framework, which can be readily applied to any type of game-based learning initiative or design. As we noted, its core components (autonomy, competence, and relatedness satisfactions) mirror those that SDT researchers have also found to facilitate high-quality learning in traditional educational contexts.

Applying PENS to Serious Games and to Virtual Educational and Training Contexts

The PENS model identifies the basic need satisfactions that underlie the properties of games that truly engage people, building on the larger body of SDT research showing how these basic needs contribute to greater interest, engagement, and performance outside games, including in classroom (e.g., Ryan & Deci, 2016; Tsai, Kunter, Ludtke, Trautwein, & Ryan, 2008), health care (e.g., Ng et al., 2012), and organizational (e.g., Baard, Deci, & Ryan, 2004) settings. In our contemporary world of information, media, and on-demand entertainment, holding people's attention is no easy task. Within this crowded universe of choices, games have emerged as particularly adept at winning our attention. We have seen why: they are adept at satisfying the basic psychological needs that are so critical for sustained motivation.

We have also noted an exciting confluence: the same need satisfactions are important factors in game-based learning, gamification, and serious game pursuits (Calvo, Vella-Brodrick, Desmet, & Ryan, 2016). PENS provides a promising template for building applications that engage people effectively in nonentertainment activities such as learning and work. Yet, achieving engagement and spontaneous learning in a game is not easy. As veteran GBL developers know, it cannot be achieved simply by wrapping need-satisfying game features around an existing curriculum (e.g., Ronimus, Kujala,

Table 6.1

Some selected game features supporting basic psychological needs

Autonomy Supports	Competence Supports	Relatedness Supports
Meaningful choices (options on tasks, strategies, timing)	Easy learning curve for onboarding	Connectivity—easy communication (e.g., accessible chat features to facilitate interactions)
Informational and noncontrolling rewards for authentic accomplishments	Clear proximal goals; optimal challenges (tasks that are scaffolded for ready mastery)	Opportunities to cooperate and to help others
Rationale for activities (clear reasons for engagement)	Dense and immediate granular feedback to gauge efficacy and growth	Ready team building and "grouping" structures and team-focused tasks
Personalization (e.g., self-designed persona and personal narrative)	Feedback that is positive and/or efficacy relevant	Social networking that enables meaningful in-game interactions
Transparency of task's utility	Feedback on cumulative progress (e.g., leveling, progress bars)	Rich opportunities for knowledge sharing and crowdsourcing new opportunities and strategies
Safety/anonymity of feedback	Low costs and encouragement for retries after failure	General climate of respect and support

Tolvanen, & Lyytinen, 2014). Instead, the model requires one to think about how each feature relates to each potential need satisfaction and ensures that what is to be learned is a meaningful part of that *satisfaction cycle*.

In table 6.1, we list a selected set of considerations that both SDT and PENS research highlight as being critical to successful gamification. Most interesting about these features is that they are derived from an understanding that the motivational effect of game elements is not based on naive ideas such as "games should be fun" or "people like rewards." Rather, PENS suggests that every gamelike feature one applies to learning will generally work or fail to work because of its functional relations with basic psychological need satisfactions or frustrations. Thus, a game's reward mechanics can be engaging, but only when they don't feel like they are controlling or incentivizing. They can work when they feel like authentic competence feedback, but not when they feel like external rewards to keep one playing. Similarly, setting explicit goals can be motivating when they have a rationale that can be autonomously embraced, yet they can undermine when they feel imposed or too difficult to reach. Competitive structures can be engaging, but not when there is extrinsic pressure to win. In fact, the impact of nearly every element of game design can be seen as a function of its relations to basic needs and thus its effects on intrinsic motivation and autonomy.

Learning as the Goal but Not the Focus

The elements in table 6.1 are just a sampling of the types of features one considers when thinking about gaming through the lens of the basic psychological needs specified within PENS that drive high-quality engagement. These are considerations that often would not follow from the frequent practice in game-based learning and gamification in which one takes some desired goal or outcome (e.g., learning math) and inserts it into a game.

People can easily sniff out when someone is trying to manipulate them by mixing unappealing goals and tasks into a game. As Flanagan has argued, “In play, the aim is play itself, not success or interaction in ordinary life” (Flanagan, 2009, p. 5). In serious games, the ordinary life goals are often far too salient. That is how educational games can fail at their dual tasks of both motivating and encouraging deeper learning. It turns out that for many of the reasons we discussed, wrapping fun around a nugget of learning is hard to do successfully.

A better strategy in GBL initiatives is to keep basic needs as the focus. In good educational games, people *autonomously* choose to learn material to achieve and seek greater mastery or performance. Contrast that with the typical educational game that offers a treasure chest of badges and awards, which one gets for solving an algebra problem or labeling the parts of a human heart. This kind of contingent reward structure only serves to highlight that the game is trying to make one learn. It underscores that one is being manipulated, and it creates a sense of being controlled, undermining autonomous engagement.

This was demonstrated by McKernan et al. (2015), who applied SDT to an analysis of two versions of the same educational game. In one version, the game was loaded with such contingent rewards, whereas in the other version these rewards were not included. Results showed that the presence of extraneous rewards added nothing to the learner’s engagement in the game—engagement is a function of having rewarding experiences rather than of being rewarded.

Where many serious games miss the mark is that they assume that because learning or work is the goal, it needs to be the *focus*. In contrast, if the focus is on the game and enhancing that experience in meaningful ways through learning, there are many opportunities for highly motivating experiences. As it turns out, what keeps people engaged with great entertainment games is also what deepens their interest, learning, and performance as well.

Consider for example the serious game *Darfur Is Dying*. This game has many of the elements of a traditional game. One gets to choose one’s character and family members, who must then accomplish quests such as foraging for water while dodging militia. There are goals and challenges that are one's focus, but the important *incidental learning* here is that there are endless challenges, and ongoing struggles and suffering, providing one with a perspective on life in Sudan. In fact, its difficulties make it a game few would long persist at, but it succeeds at its task of raising awareness.

A key to game-based learning—and indeed serious games more generally—is bringing a complex set of skills (or a raft of knowledge) into a constrained environment where they can be explored, manipulated, analyzed, and ultimately assimilated. By attaching functional significance to learning information that links that learning to need satisfaction in a gaming context, learning becomes interesting and even fun. This returns us to the idea that fun does not aptly describe most good video games, even those that are purely for entertainment. While the goal of entertainment games is to have fun, the most successful games achieve this by focusing on engagement by providing a dense matrix of opportunities for experiencing autonomy, competence, and relatedness. These opportunities can be rich in information, and deeply exploratory and investigative, because all these are aspects of intrinsic motivation. It is by their ability to supply experiences of choice and autonomy that games can enhance the quality of learning outcomes. Where they include controlling elements, such as evaluations, extrinsic rewards, and social comparison leaderboards, they can unwittingly communicate to learners that the learning itself really isn't that interesting and undermine intrinsic motivation (van Roy & Zaman, 2017). In a well-designed game, the learning becomes its own reward.

Beyond rewards, consider another parallel finding in research on motivation outside games. There is much educational literature suggesting that a focus on *mastery goals* (improving your own skills) rather than *performance goals* (e.g., trying to do better than others) is generally more effective at engaging students and getting results (e.g., Krijgsman et al., 2017). Whereas feedback in so many educational environments is performance focused, and thus often demotivating, good video games already have a template that is aligned with optimal learning: game structures are engineered so one can visualize one's own progress in skills, achievements, or capacities.

One common example from gaming that we have noted is the inclusion in games of a leveling mechanic that affords a scaffolding for incremental growth, ability, and range of opportunities. These systems work by providing clear distal goals alongside the more immediate feedback one receives for successful actions. Important also is that leveling provides experiential rewards that function *within the game* rather than being external and contingent incentives that will typically undermine intrinsic motivation. Such technologies also customize the learning experience in a way that is mastery oriented rather than performance oriented. This mechanic has clear advantages over performance-based (i.e., normative and comparative) evaluations, so common within traditional learning environments, and highlights the natural alignment between successful games and well-researched learning strategies.

Within a highly successful school reform approach called First Things First (Connell & Klem, 2006), a leveling approach was developed for students taking ninth-grade math—a pivotal moment in terms of dropout or persistence in US urban schools. All the math skills for the year are broken down into just over one hundred "I can" statements, each representing a kind of quest or proximal task. These are sequenced from easy to hard, so that each skill builds capacities to master another. Math thus consists of mastering each skill in sequence, and when you show you "can," you level up. No need for those pesky tests. If you fail at the task, you can go to a "math café," where there is tutoring support. Then, as in video games, you get to try the quest again. This is a pure mastery system and, not surprisingly, students like seeing their progress and can experience much more growth in competence satisfaction than when simply being graded on tests and finding out whether they passed. Here a game feature replaces the tried but untrue motivational strategy of normative grading (Ryan & Deci, 2016, 2017). In fact, game designs are forgiving in a way that too many learning environments are not. Punishments for failure in games are usually small and temporary—in schools and organizations, they can be demeaning and costly. Instead of punishing repeated efforts, games reward retries and persistence. Educators have much to learn from games' less controlling frameworks.

Summary and Future Directions for Research

The motivational model we have outlined can serve as an important tool in the design and implementation of game-based learning strategies. Nonetheless, we recognize that in any learning or training program that applies game-based learning there are plenty of complex issues to resolve. Similarly, there are research questions concerning the motivational underpinnings of game-based learning that remain unanswered. In these final comments, we consider several topics relevant to future directions in research on game-based learning and its applications.

First, we discussed the importance of intrinsic motivation to optimal learning, but many practicalities in learning environments can pose threats to fostering this type of high-quality motivation. As just one example, in learning settings, it is often deemed important to hold students or trainees accountable for reaching assigned goals or objectives. Navigating these motivational waters can be difficult, especially insofar as concepts such as incentives and grades are so naturally associated with, and too often assumed to drive, educational attainment. Applying a motivational model of games such as PENS might assist in better solving such challenges. For instance, we explored how games can deepen experiences of competence by providing highly accessible informational feedback on progress that enhances feelings of competence and mastery. Conveniently, these mechanisms are also markers of progress in mastering content and material. Such game mechanics—artfully applied—can inform how evaluations of learning might be integrated into learning tasks without undermining intrinsic motivation. In a similar way, game-based learning designs can be brought to bear to research other complex issues learners face in today's traditional classroom and organizational environments, including the potential to increase engagement through innovative strategies for granular feedback, provision of choice, and multilearner interaction opportunities.

Second, game-based learning and related approaches (e.g., gamification) seek to enhance learning and healthy development by leveraging the strong motivational properties of games, and in particular the intrinsic need satisfactions that characterize high-quality learning. Evidence specifically suggests that virtual experiences can engage us, teach us, and provide support most effectively when they facilitate intrinsic motivation and autonomous self-regulation. However, the specific mechanistic processes through which this enhancement works remain largely underexplored. Luckily, examination of the links between intrinsic motivation and autonomy and their mechanistic underpinnings is an especially active area of current research (e.g., see Miura et al., 2017; Ryan & Di Domenico, 2017). Continued studies of the specific neural mechanisms associated with intrinsic motivation in particular will continue to inform studies of development and learning. Game-based learning supplies an especially apt arena for such explorations because elements of games can be readily manipulated experimentally and assessed for the neurological changes they produce.

Related to this, although there is a rich body of literature supporting motivational elements with regard to broad learning outcomes in applied settings, there has been too little experimental work on the microcognitive underpinnings of these learning advantages and their relations with specific motivational factors. More research on those aspects of learning processes and outcomes that are enhanced by these motivational factors and satisfactions is thus another future agenda. In addition, more research on how motivational processes relate to discrete emotions, and their phenomenological and attributional correlates, will enrich process approaches to education and training.

In any well-crafted school or training program, we also suggest that merely enhancing experiences of cognitive competence is not enough to sustain either ongoing engagement or performance. Indeed, research in educational settings outside gaming consistently shows that learning is better sustained and performance is enhanced when learners can feel not only competence or mastery but also autonomy and connectedness in the process of learning (Ryan & Moller, 2017). This aligns well with what the PENS model has found to be at the heart of successful video games. Thus, a third general area for continued inquiry is how autonomy, relatedness, and competence both independently and interactively contribute to motivational and cognitive outcomes in game-based learning contexts. Here again, game formats afford unique opportunities for controlled experiments on these complex relationships.

Finally, just as smartphones in the classroom did not exist a decade ago, new technologies are constantly emerging that can disrupt learning or quickly render approaches to game-based learning quaint or outdated by the learners they seek to serve. Yet it is noteworthy that the motivational model outlined here has remained relevant and predictive in the field of video games for more than 15 years, even as new technologies (such as mobile devices and social networking) have emerged and deepened. As of this writing, even newer technologies that hold great promise for game-based learning, such as virtual- and augmented-reality devices and platforms, are moving into the mainstream. Our ability to harness these technologies as the next generation of tools for game-based learning will no doubt be facilitated by applying the principles of intrinsic motivation and tools such as PENS (Peters, Calvo, & Ryan, 2018). Because this framework is agnostic to any specific technology or design, we suggest it can be readily applied to these new and emerging technologies to enhance both engagement and learning.

Educators have always understood the need to actively engage learners in order to foster greater persistence and deeper learning. Game-based learning offers many opportunities for both agentic and interactive learning, potentially adding much value to educational efforts. As summarized in this chapter, a focus on intrinsic motivation and the basic need satisfactions that support it can greatly contribute to this movement by helping guide designers in building features that enhance sustained engagement and by empowering them to carry motivational best practices into ever-newer game technologies.

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7 Sociocultural Foundations of Game-Based Learning

Constance Steinkuehler and A. M. Tsaasan

Conceptualizing Sociocultural Foundations for Game-Based Learning

From a sociocultural perspective, the fundamental vehicle for learning is social interaction. Cognition is not solely an internal event but rather a process of internalization from cultural to cognitive; socially shared processes, realized as material and discursive interactions, are internalized to become internal cognitive processes: "Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). … All the higher functions originate as actual relationships between individuals" (Vygotsky, 1978, p. 57). Thus, learning is an ongoing process of *enculturation*. According to Bruner, "Culture is constantly in [the] process of being recreated as it is interpreted and renegotiated by its members" (Bruner, 1987, p. 123), so learning happens within a society "whose future shape we cannot foresee" (p.121). What constitutes membership within a given community then is always in flux and is determined by those within it at the time, so enculturation itself is an ever-evolving process of changing relationships.

From this perspective, learning makes sense only within a given community of practice (Lave & Wenger, 1991; Wenger, 1998), a culture or "discourse" (Gee, 1990) if you will. A discourse is "a socially accepted association among the ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group or 'social network'" (Gee, 1990, p. 154). Within this given discourse, enculturation is something done socially and materially, through semiotic and other means, that results in the slow process of identity transformation from inexperienced novice to recognized expert. This focus on identity is important. According to Holland, "Identity is a concept that figuratively combines the intimate or personal world with the collective space of cultural forms and social relations … lived in and through activity" (Holland, 2001, p. 5). Learning is the progression and transformation of an individual along "trajectories of participation" (Greeno, 1997) and growth of identity within a given community of practice (Steinkuehler, 2006a).

The scope of our inquiry therefore goes beyond the game itself and into the game world, or meta-game: "Bruner's approach … [is often used] as a means of better specifying the ways that a game can be viewed as a … *tool* … [s]hifting … focus on the fundamental nature of the game to the activities of gamers around the game" (Duncan, 2010, p. 23, emphasis in original). When we extend the scope to the meta-game, we find the ways in which other players are integral to the game world and the learning process. From our perspective, the community developed around the game not from the void but from would-be players from existing trajectories. Interest drove their movement toward the game community and, as time passed, a distinct culture emerged that was interwoven with digital and corporeal elements, a separate social model tethered to the gameplay. It is the goals for learning valued within this community on which success metrics ideally are based and toward which authentic learning opportunities develop. Designers should attend closely to the resulting meta-game to gather insight into their player community's learning in the wild.

Three particular mechanisms for learning that are evident when we include the meta-game are mediation, modeling, and apprenticeship. *Mediation* refers to a transformational process where signs, tools, or practices of a given community are internalized by an individual, as evidenced through changes in behavior: "[Mediation] is the key in [Vygotsky's] approach to understanding how human mental functioning is tied to cultural, institutional, and historical settings since these settings shape and provide the cultural tools that are mastered by individuals to form this functioning. In this approach, the mediational means are what might be termed the 'carriers' of sociocultural patterns and knowledge" (Wertsch, 1994, p. 204). *Modeling* refers to cognitive or material (here, digital) practices and attitudes that are on display, intentionally or otherwise, by experts as examples of target behaviors for learners to emulate. "Most human behavior is learned observationally through modeling: from observing others one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action" (Bandura, 1977, p. 22). Finally, *apprenticeship* is joint, scaffolded activity between an expert and a novice in which the novice's skills are developed in conjunction with explicit expert support along a trajectory of mastery. Here, "the interplay between observation, scaffolding, and increasingly independent practice aids apprentices both in developing self-monitoring and correction skills, and in integrating the skills and conceptual knowledge needed to advance toward expertise" (Collins, Brown, & Newman, 1987, p. 3). All three mechanisms—mediation, modeling, and apprenticeship—are vehicles through which the learner adopts the knowledge, skills, and dispositions of the community and, as such, gains status within that community. All three are also particularly ripe concepts for the study of learning through games.

A sociocultural perspective requires a native community, so a sociocultural foundation for game-based learning requires a game that is chosen by the community. The game must be noncompulsory, beyond the straw man's choice of "this or reading a textbook"—the interest must be authentic. The learners must be driving adoption, for example by inviting their friends—demonstrating authentic interest. The distinction between voluntary and compulsory is one of the most important distinctions in the application of sociocultural lenses to "games for learning" and "serious games." This chapter focuses on games that are voluntary and interest driven—enmeshed within an affinity space—from a sociocultural perspective.

Rationale for Sociocultural Approaches to Game-Based Learning

Games are not merely designed objects; they are a "mangle of play" (Steinkuehler, 2006a), a combination of both designed software and emergent culture. In their design, whether consciously or unconsciously, the norms, values, and fundamental belief systems of the human designers are embedded in the form of rules, images, accepted inputs, financial structures (e.g., one-time cost, ongoing subscription fee, in-game purchases, etc.), and myriad other essential components of bringing a video game title to an audience. Yet, in addition to the values manifested in the software code, gameplay is crucially informed by the cultural norms embedded in the fandom, the "meta-game" that emerges from play over time. Multiplayer games are perhaps the more salient examples of the overt reliance of games on peer sociality and joint play, yet the same property holds for any title with a substantive following. Games create affinity groups (Gee, 2005) that reflect and shape the game rules, communicating these rules in and across various spaces (often digitally mediated) within the game world. Thus, understanding games demands understanding their intellectual culture of play and the transmedia nature of that particular culture.

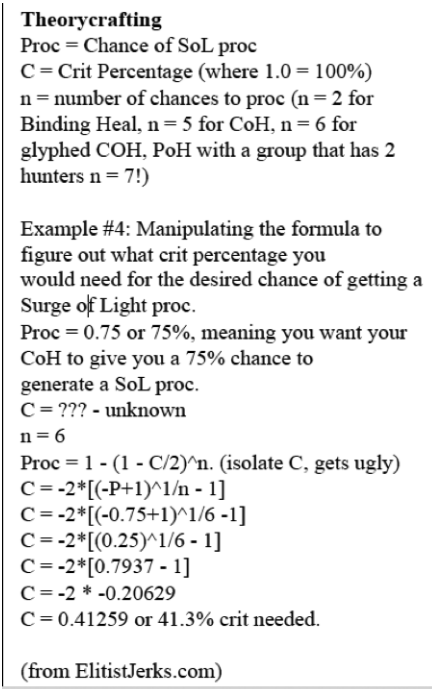
Methodologically, games provide a transparent medium for examining and understanding the bidirectional influence of self and society that is at the core of sociocultural studies of learning. First, because games are, at heart, systems, they are "especially good at communicating relationships: digital games are most immediately about the direct relationship between the player's action or choices and their consequences" (Anthropy, 2012, p. 20). Second, by "provid[ing] a representational trace of both individual and collective activity and how it changes over time, games [enable the educator or] researcher to unpack the bidirectional influence" (Steinkuehler, 2006b, p. 97) of individual members and the community. This in turn presents myriad possibilities (and demands) for developing meaningful evaluation metrics tied not just to the individual appropriation of cultural knowledge, skills, and dispositions (i.e., traditional common formative and summative assessments) but in return how the individual shapes and influences the culture in which he or she participates (i.e., authentic and community-based assessments). In this way, the promise of game-based learning is the study of learning as a form of social knowledge construction whereby a community of players develops new knowledge in the context of a digital medium that, by design, provides explicit, ongoing, and situated evaluation and feedback on increasing individual proficiency within the game mechanics themselves. Identity development from novice to contributing community member is the basis for measuring success.

An Example

Sociocultural analyses of learning through games are perhaps best illustrated in terms of the mechanisms for learning defined earlier. Here, we illustrate meditation, modeling, and apprenticeship via three case studies across three separate game titles. Each illustration arises in its own distinct cultural play context: the first (mediation) in the context of the massively multiplayer online fantasy game *World of Warcraft* (Blizzard, 2018), the second (modeling) in Disney's public servers for (the now defunct) *Disney Infinity 3.0* (Disney Interactive Studios, 2016), and the third (apprenticeship) in the context of the massively multiplayer siege-based Korean game *Lineage II* (NCSOFT, 2018).

Mediation In a case study of *World of Warcraft*, Choontanom and Nardi (2006) examine community "theorycrafting," a culturally shared "intellectual activity involving hypothesis generation, testing, numerical analysis, logical argumentation, rhetoric, and writing. It is collaborative; theorycrafters work together to gather and analyze data and post their results in public forums to inform theorycrafters and ordinary gamers of their findings—and sometimes to engage in heated debates" (Choontanom & Nardi, 2006, p. 187) in game-related forums and blogs. *World of Warcraft* is a complex, massively multiplayer online (MMO) game that was initially launched in 2004 and has evolved since then. As the game's software changes, its community of players must change as well. Players need to keep pace with the increasing demands of updated content in order to understand the game and then, through this understanding, transform themselves into more proficient players and contributing members of the community. Theorycrafting serves as one means for developing shared understanding of the complexities of the game and sharing that understanding with the player base at large; it is sociocultural knowledge construction done explicitly, over time, and collectively via posts, graphs, images, equations, and debate. It is the engine that generates advanced gameplay strategy and understanding; as such, it is tied to status in the community of players and regarded as "elite." It is no coincidence, then, that one of the most famous theorycrafting websites is named "Elitist Jerks." This is the community resource that Choontanom and Nardi investigated.

In their case study, Choontanom and Nardi (2006) show how theorycrafting as a practice and a resultant body of knowledge *mediates* players' participation in the game, providing the cultural tools for individuals, both authors and readers alike, who use the online texts, diagrams, and mathematical arguments as fodder for gameplay and debate. Individuals "calibrate" to one another's understanding and interpretation of



Theorycrafting
Proc = Chance of SoL proc
C = Crit Percentage (where 1.0 = 100%)
n = number of chances to proc (n = 2 for
Binding Heal, n = 5 for CoH, n = 6 for
glyphed COH, PoH with a group that has 2
hunters n = 7!)

Example #4: Manipulating the formula to
figure out what crit percentage you
would need for the desired chance of getting a
Surge of Light proc.
Proc = 0.75 or 75%, meaning you want your
CoH to give you a 75% chance to
generate a SoL proc.
C = ??? - unknown
n = 6
Proc = 1 - (1 - C/2)^n. (isolate C, gets ugly)
C = -2*[(-P+1)^1/n - 1]
C = -2*[(-0.75+1)^1/6 -1]
C = -2*[(0.25)^1/6 - 1]
C = -2*[0.7937 - 1]
C = -2 * -0.20629
C = 0.41259 or 41.3% crit needed.

(from ElitistJerks.com)

Figure 7.1
Theorycrafting on ElitistJerks.com. Image: Dr. Bonnie Nardi.

the game and its practice through situated language use in the context of joint activities, within the game and outside it in fan forums. Thus, theorycrafting as a mediational means creates intersubjectivity (Tomasello, 2003) among players—shared conceptions of, practices within, and values of the game.

Modeling In the case of *Disney Infinity 3* (now retired), Brown (2017) considers the development of secondary discourses through a New Literacies (Knobel & Lankshear, 2007) lens, where players learn, remix, and re-create games for others. For many children in the United States, Disney narratives and characters replace traditional folk tales and are entangled in their primary literary discourse from home. Unlike the Hans Christian Andersen (Andersen, 1890) and Brothers Grimm (Worthy & Bloodgood, 1992) retellings, however, in Disney versions the Little Mermaid lives and Cinderella's sisters retain all the parts of their feet. Disney historically has been protective of its trademarked characters, but *Disney Infinity 3* (*DI3*) was explicitly designed with user-generated content in mind: players used Disney's characters, narratives, and settings from various copyrighted worlds to play the game and as the materials for creating

Figure 7.2
The Magic Wand tool reveals details and allows interaction with game levels designed by others. Image: Jamie K. Brown.

new levels within the game for others to play. Here in *DI3*, Rudyard Kipling's Baloo is Disney's Baloo and could very well don Buzz Lightyear's jetpack to complete a quest with Alice and the Mad Hatter. Such mashups were frequent and playable. Players would upload their creations to Disney's community servers or via peer-to-peer sharing directly with friends. Other players and Disney Infinity developers would then engage with that content, providing feedback and "up voting" based on their review and evaluation. Thus, as the learner progressed from game player (content consumer) to game creator (content provider) over time, *DI3* made community validation explicit through sharing that new game content with peers and authority figures for review, evaluation, feedback, and acceptance. In-game peer review was enabled through the Toy Box Hub and Magic Wand.

Brown (2017) took a sociocultural approach to unpacking "what it is to make meaning in areas where digital technologies have afforded the creation of texts that are different at a fundamental level" from linear print text (Brown, 2017, p. 79), detailing how players, by sharing their remixed creations, modeled their interpretation of what it means to build a good game. With the Magic Wand tool, others can then, at their own pace, deconstruct that good game. Here, modeling is taking place asynchronously. One player builds the game, shares it, and then another player picks it up and takes it apart to see how it works. This level of granularity is rarely available when modeling, say, how to change the oil in a car properly (and without making a mess). In primary schools in the United States,

> children often construct stories by filling in the blanks of a pre-constructed paragraph with words. The pre-formed paragraph acts as a type of scaffolding, prompting and guiding the developing writer. We can view the elements of storyworld [in *DI3*] presented here as such a tool. … Disney Infinity attempts to encourage New Literacy practices at two levels. … [P]layers are encouraged to participate in play, appropriation, and transmedia navigation to get them to understand and become comfortable with constructing user-generated levels known as Toy Boxes. On a higher level, the actual construction of the Toy Boxes requires practicing these same literacies. (Brown, 2017, p. 70)

Apprenticeship In a discourse analysis of in-game talk, Steinkuehler and Oh (2012) examined peer-to-peer apprenticeship practices across three game titles—*Lineage I*, *Lineage II*, and *World of Warcraft*—all massively multiplayer online role-playing games that rely on a strong player base in order for the games to thrive. Given the nature of the game mechanics, players (especially "guildmates") are incentivized to increase the in-game skills of others. As a result, apprenticeship practices arose across all three titles as a natural and spontaneous part of gameplay. It is a community learning practice pivotal to MMOs, where the population of players and their emergent community of practice are required for the game to function. New players must learn the goals, and the ways in which those goals are achieved in practice, from the players with whom they interact, in order to transition from peripheral participant to fully contributing member.

Using discourse analysis on text exchanges in the in-game chat window, coupled with character action within the main 3-D world, Steinkuehler and Oh (2012) demonstrate how apprenticeship sequences across all three titles share structural commonalities that mirror those found in face-to-face, traditional apprenticeships across the literature: joint activity, situated feedback, just-in-time information, expert modeling and scaffolding, and direction of attention. By attending to the details of interaction within the game, the authors show how apprenticeship into the common, valued practices of the game in fact also serves as apprenticeship into what to value and how to value certain forms over others, thus highlighting the nonneutral role of enculturation discussed earlier.

Learning Outcomes from a Sociocultural Perspective

Learning outcomes from a sociocultural perspective are community defined. Here, we take for granted that the goals of learning are, at their root, culturally determined, not natural categories, and that there are multiple discourses to which one belongs and therefore multiple identities (Cazden et al., 1996). In this way, all learning is fundamentally social and cultural (and political). Every community has its own system of meaning, which includes not only language, signs, and symbols but also ways of interacting with symbols, tools, and other members (practices), and ways of valuing (dispositions). Expertise, then, is skillfulness in the knowledge, skills, and dispositions that are most valued by a given community, be it particle physicists, Scientologists, amateur knitters (or "hookers," their crocheting counterparts), professional wrestlers, corporate lawyers, Trump supporters, or esports enthusiasts. It is fluency in a *discourse* (Gee, 1990) that requires not just mastery itself but also recognition by other community members as one who has mastered it. It is status within the given community, culturally bound (relevant to a given community, not the world), and inherently political (tied to the distribution of resources such as access and goods). Thus, learning is as much about context, recognition, and politics as it is about using the "right" knowledge in the "right" way at the "right" time (cf. Apple, 2004), so it follows that in game-based learning, outcomes are seen as identity changes within a given community, reflected in game proficiency and interactions within the community.

Synthesis of the Literature

The diverse work of 33 scholars was included in this literature review. The composition of game-based learning research is heterogeneous across multiple axes, including the academic disciplines of researchers, the variety of participant populations, and myriad data and methods, with most studies large in scale (data volume) and longitudinal. From across the fields of anthropology, comparative literature, computer science, education, informatics, psychology, and sociology, researchers are interrogating, and at times adopting, each other's study designs, data collection and analysis techniques, and logical arguments for understanding results. The interdisciplinarity of the domain space is significant enough to note, and the impacts are complex enough to go beyond the scope of this chapter. The second axis, study participant heterogeneity, and its implications within game-based research, also warrants volumes of its own. However, in this chapter, participant population compositions will be discussed to the limited degree to which they were explicitly identified as impacting study design and data collection and analysis, and when they were germane to findings.

Game players have diverse communities. All humans (and, some argue, other mammals) have grown up playing some form of game (Burghardt, 2005; Caillois, 1958/2006). The studies included in this chapter include diverse learning communities that vary in terms of their members' age, sex, nation of origin, socioeconomic status, location, and levels of proficiency. In this chapter, we focus on digitally mediated games, which, by the nature of the medium, raise barriers to participant inclusion that require researchers to explicitly address issues of *access* to material and nonmaterial resources. The third axis of heterogeneity, the surprising manifold data types and methods, will be discussed in terms of limitations and implications after the examination of extant themes across the literature. The variety in gameplay output provides a vast array of possible data points. From individual keystrokes to chat logs, digital game data can provide a wide range of collection opportunities. The variety, including variety of scale (e.g., actions occurring within fractions of seconds or over hundreds of hours), makes big

Table 7.1

Common themes across the literature, organized according to three main postulates

	Collaboration is the intervention.	Games are intact activity systems.	Standard relationships of power and status are reorganized.
Roles	Learning as identity change	Consistent focus on social interaction (and thus language)	Fluid teacher-learner roles
	Learner interest drives interaction	Learning is active and hands-on, not passive "traditional classroom" style	Hierarchy based on knowledge/helpfulness
Location/scope	Learning is accomplished through social interaction	Digital and corporeal features are seen in synthesis	Recognition of meta-game and its renegotiation
		The game is the platform on which communication and activity occur (the context)	
	Learners' contribution to the community is the goal (and justification) of learning.	Games as a place/space: Games as a nexus of practice	Otherwise marginalized learners are recognized as successful in game communities.

data methods available wherein the hardware and algorithmic limitations become visible constraints. Game scholars employ not only developer-provided data collections but also third-party collection and analysis tools, in addition to developing their own tools and techniques in this rapidly accelerating data landscape.

Across the work of the 33 scholars included in this review, we found 13 themes, which can be organized into three basic postulates: (1) collaboration itself is the intervention in learning through games; (2) games are intact activity systems distributed across people, places, modalities, and texts; and (3) standard relationships of power and status are reorganized. Through the work of game-based learning scholars, we see patterns in case studies where power, agency, and authority are negotiable within gameplay and community interactions. Table 7.1 details the emergent themes across the literature (columns) and the facets of sociocultural concern: the roles of individuals within the community, and the location and scope of the interaction being studied. Note that the order here does not indicate importance or degree of concern.

Collaboration Is the Intervention

Sociocultural studies of game-based learning consider cognition at the intersection of the individual and the cultural. A game's culture, or game world, includes meta-game activities and can be seen as "collaboratories"—"moving target[s] … [where] key elements are an orientation to information flow between instruments, people, and documents embedded in an integrated information infrastructure" (Bowker & Star, 2001, p. 33). A learner co-constructs an information flow when pursuing knowledge acquisition within the game community. Here, collaboration is the intervention, and the game world is the platform for communication among community members. Tomasello, Kruger, and Ratner (1993) argue that cultural learning falls into three broad forms—imitative, instructed, and collaborative—where imitation and instruction are necessary stages of development toward proficiency that allows for collaboration. Imitation and instruction are not in themselves sufficient activities to signal contributing membership; rather, full membership within a game world is demonstrated through collaboration. Over time, game scholars have provided theoretical and empirical work across these forms, often addressing the ways in which all three manifest in a single game world, allowing players to progress seamlessly within a particular world model or learning ecosystem.

The roles of individuals within a given culture demonstrate their position in relation to others, with shifts in roles divulging underlying learning progressions (Black, 2006; DeVane, 2014; Gee & Lee, 2016). Learning in this way is reflected in identity change, "an avatar wearing powerful items, for instance, is essential to the construction of a player's identity. It broadcasts the player's status to others" (Ducheneaut, Yee, Nickell, & Moore, 2006, p. 414). Rebecca Black examined second-language acquisition and the transitions of new language learners to mastery on fan fiction sites, noting patterns of knowledge acquisition and its reflection in changes to social status, like that of a young native Mandarin Chinese speaker developing mastery of English to the point where they were "able to achieve the identity of a successful and wildly popular author in this [English language] space" (Black, 2006, p. 173).

Collaboration within games is a voluntary proactive interaction; it is interest-driven learning. Ethnographic accounts of various gaming communities describe primary drivers of knowledge acquisition as player interest (Holmes, 2015; Jenkins, Purushotma, Weigel, Clinton, & Robison, 2009; King, 2013; Nardi, 2010; Stevens, Satwicz, & McCarthy, 2008). Learners like the students in Kurt Squire and Sasha Barab's astronomy simulation game case study "are considered active participants in the learning process, setting their own learning goals (in relation to the task) and forging meaningful relations through their experiences" (Barab et al, 2000, p. 723). From players gathering in convention centers for collaboration, socialization, and "play between worlds" to sharing strategies for setting up and running multiple computing systems simultaneously in order to "power play" games, learners seek out and—if need be—create contexts to move their mastery level forward along their desired trajectory of participation within the game world (Taylor, 2009/2012).

In this way, game-based learning happens in collaboration with others. "Young people learn and teach together while playing video games" (Stevens, Satwicz, &

McCarthy, 2008, p. 45). In team games, individuals “take on a specialized role as determined by game mechanics, specific monster battles, and group norms” (Chen, 2009, p. 47), and success (and failure) is a collective interdependent achievement. Here, mediation, modeling, and apprenticeship practices are viewed as a regular and normative part of everyday play. In much the same way that the style of play of sports professionals is mimicked by novice players, in games we find mastery accorded a kind of celebrity status within a game community. For example, in *Minecraft*, “the practice of modeling on celebrity players hints at a broader, assumed community of practice for different players who sense a legitimate way to play or seek to model their practices on who they view as core members of a *Minecraft* community” (Pellicone & Ahn, 2014, p. 191). Other examples that provide a space for collaboration in “games for learning” include titles from the University of Washington Center for Game Science, such as *Foldit* (University of Washington Center for Game Science et al., 2018) and *Mozak* (University of Washington Center for Game Science, 2018), *Crayon Physics Deluxe* (Kloonigames, 2018), the group learning game *Atlantis Remixed* (Center for Games and Impact, 2018), and *Algodoo* (Algoryx Simulation AB, 2018). Again, learner contribution to the community is the goal of learning. Whether this contribution is an in-game object such as a purple potty added to the inventory options in the game *The Sims 2* (Electronic Arts Inc., 2018), a numerical analysis of options on a *World of Warcraft* forum, or a new game level on a *Disney Infinity 3* server, players’ contributions to the game world are part and parcel of learning.

Collaboration is an indicator of expertise. Learners who have achieved mastery can be identified in their forms of contribution. In the purple potty example, the digital object was designed as a gift for the learner’s grandchild to use in playing *Sims 2*. The existence of the potty, its essential game qualities, and its position within the general inventory signal that the community member is an expert in the community. The collaboration between the grandparent and grandchild is the learning intervention within the game, which serves as a platform for interaction. The potty fits within the game mechanics and the community norms, and it identifies the creator as a contributing member of the community.

Games as Intact Activity Systems

The game as an intact activity system that includes the game, texts, and community has been found to function as a vehicle for learning in the virtual/corporeal borderlands that people regularly inhabit. Case studies often triangulate data generated by participants in the game, in the game world, and in person with a consistent focus on social interaction (and therefore language): “Through repeated assessments of participants’ knowledge and understanding of key literacy practices related to gameplay and their attitudes and progress in the game versus at work, home, and school, we can trace the trajectories of learning (Greeno, 1998) of participants within such communities and how such literacy practices are situated in the everyday and offline lives of gamers" (Steinkuehler & King, 2009, p. 51).

Game-based learning is active, hands-on, and driven by learner-initiated interactions to accomplish a self-determined learning goal (Gee, 2005; Martin, 2012; Oblinger, Oblinger, & Lippincott, 2005; Squire & Jenkins, 2003; Steinkuehler & Duncan, 2008; Turkay & Adinolf, 2012). Unlike in traditional passive classroom learning contexts with heavy emphasis on "skill-and-drill test preparation" (Hayes & Gee, 2010, p. 185), failure is common in hands-on learning and an expected feature of gameplay (Juul, 2013). Failure is a component of community norms around trial and error that is often explicitly supported (and empathized with) by other players. Games and their affinity spaces are where learners share content and give and receive feedback: "Not only do [online] affinity spaces offer insight into such literacy practices, they also show that young people value project-based, self-directed opportunities to share their creative work with an authentic audience" (Lammers, Curwood, & Magnifico, 2012, p. 55).

In considering game worlds, the digital and corporeal features are seen in synthesis, as facets of the same learning experience; they are part of the same activity. Sociocultural studies demonstrate a consistent focus on socially shared processes, which include language in a variety of interaction modes, many of them digitally mediated and realized as material and discursive interactions. A separation of digital and corporeal modalities was prevalent in scoping early human-computer interaction research for narrowly targeted feature development, as seen in the early "Computer-Human Interaction" research conferences, which still carry the legacy naming convention CHI, while the field has gone on to reorder the terms to the contemporary HCI, human-computer interaction. The artificial delineation of the tools and the interaction with those tools in the wild is not only antithetical to sociocultural understandings of digitally mediated learning systems but also has retarded pedagogical progress writ large. In game-based learning, humans, hardware, and software are part of the mangle of play and are generally considered a holistic system of relationships where digital and corporeal features are seen in synthesis, as John Dewey reconceptualized an "aesthetic experience—an active, participatory relation to artful material and collective activity" (Nardi, 2010, p. 41). To explain further, "To understand aesthetic experience, we cannot stop at analyzing an artifact as a text, or narrative or set of functions or composition of elements, but must also undertake to examine the actual activity in which the artifact is present" (p. 43). The aesthetic experience transcends the game to include people, places, modalities, and texts within what it means to play the game.

The game is the platform for communication and activity to occur (the context). In their study of *World of Warcraft* online forums, Steinkuehler and Duncan noted that, "Eighty-six percent of the forum discussions were posts engaged in 'social knowledge construction' rather than social banter. Over half of the posts evidenced systems-based reasoning, one in ten evidenced model-based reasoning, and 65% displayed an evaluative epistemology in which knowledge is treated as an open-ended process of evaluation and argument" (Steinkuehler & Duncan, 2008, p. 530). These are noncompulsory learning practices; they are the social experiences players are seeking in order to progress along their trajectory of participation. These forums then are also spaces that provide game design feedback on features interesting to player communities.

From the sociocultural perspective, games are a nexus of practice commonly considered third places (Ducheneaut, Moore, & Nickell, 2007; Steinkuehler & Williams, 2006), democratic locations where anyone can enter and, given that they are interested, learn the social norms, demonstrate they belong, and remain as regulars. Gee and Hayes (2010) describe the case of a retired computer instructor who moved from marginal game-world member to recognized master in the process of playing *Sims 2* with her grandchildren. This role transition grew from the simple desire to create a purple potty for her granddaughter to use in the game but developed along a self-driven and self-orchestrated trajectory of participation to acquire the mastery necessary to play with her family in her preferred role. Games designed for learning with a focus and features supporting broader community interactions include *Minecraft: Education Edition* (Mojang, 2018), *Aucraft* (Duncan, 2018), and *Atlantis Remixed* (Center for Games and Impact, 2018).

Broadly speaking, when we talk about game-based learning as an intact activity system, we mean a system that includes not only the activity within the game itself but also the texts and community that are part and parcel of the game experience. From a sociocultural approach, when designing a game for learning, the design process should be centered within the community. Designers should align the game goals with the community's values for what should be learned. Metrics for success should be community defined, and feedback data points should be triangulated and include interactions with the game, texts, and community in order to understand the opportunities and affordances of a particular game-based learning system.

Standard Relationships of Power and Status Are Reorganized

A particular community determines what is and is not an appropriate goal for various learners at various moments, dependent on various tangible and intangible resources and their patterns of movement. The emergent values embedded in social and cultural (and political) systems then inform and codetermine valued learning content, methodologies, and opportunities. The distinction between novice and expert is the demonstrated fluency in the knowledge, skills, and dispositions that are most valued within the given community. Demonstrating fluency requires not just mastery itself but also community recognition of mastery, which politically reflects resource distribution (e.g., access, materials). Acknowledging community values is nonneutral. Development industries in the United Kingdom and United States have a history of creating markets for their technologies and ways of knowing by providing "solutions" to what they perceive as the problems of others: “Patriarchy operates through hegemony and homogenization; it takes the positions of dominant groups and adopts them as universal positions, marginalizing alternatives, erasing differences, and obscuring the particularities encoded in the universal” (Dourish & Mainwaring, 2012, p. 137). However, “multiple perspectives can be simultaneously present … open[ing] up the possibility that we might make all structural elements matters of description rather than matters of configuration, and as such, place them on similar footings without privileging any one point-of-view … suggest[ing] that the fundamental commitment to building effective technical objects does not require the sorts of representational absolutes that we are generally familiar with in conventional systems” (p. 140).

All researchers position themselves, their work, and their values through their language and demonstrated mastery of academic discourse, as we do in this volume with careful consideration. Game-based learning researchers generally play games, the assertion of their play expertise in relation to their work often included in terms of hours or months played, avatar rank, level or series completed, and/or big bosses defeated. The authors of this chapter are gamers. We have come to know, and been recognized within, our respective game worlds. We bring to our work the intimate knowledge and critical perspective of connoisseurs of game culture, while recognizing the biases and limitations inherent in our positions. We contend that these limitations are preferable to and more readily mitigated than the limits and detriments to research and design that lacks intersubjectivity, wherein researchers and game developers seek to report on and build games for domains as unknown to them as they are unknown to the subject community or culture of interest.

In the beginning of the new millennium, from within game worlds, Jesper Juul and Kurt Squire brought two of the first empirical studies of game-based learning to academia, of players by players. The themes from these landmark studies reappear in many subsequent case studies, both naturally occurring ethnographic and quasiexperimental contexts, and include observations of fluid teacher-student roles; social hierarchies based on demonstrated expertise (rather than age or SES); recognition of the meta-game and processes of its active renegotiation, including emerging spaces of pedagogical authority; and instances where otherwise marginalized learners are recognized as successful in game communities.

The fluidity of the teacher-student roles varies by game context, but the regularity with which it is reported (Anthropy, 2012; Okita, Turkay, Kim, & Murai, 2013; Steinkuehler & King, 2009; Taylor, 2009) is striking and suggests that a new form of *reciprocal teaching* (Palinscar & Brown, 1984) is a recurring theme. Duncan highlights this difference: “In many contemporary schools, students are afforded very little facility to reconfigure and restructure their learning materials (e.g., a low degree of ludic affordances) and are rarely encouraged to formulate their own narrative understandings of course materials (e.g., a low narrative affordance). … [T]here is a stark difference between activities engaged upon within ad hoc online communities and the restrictions of many contemporary curricula" (Duncan, 2010, p. 32).

Games are designed systems coupled with emergent interaction, and sometimes what emerges brings unexpected and contested change to the possibility space of interaction; here we mean "cheating." Scholars such as Mia Consalvo, Deborah Fields, and Yasmin Kafai have expanded the meta-game to include processes of its active renegotiation. Fields and Kafai note that in the game world of *Whyville* there are "cheat sites" that fall along a continuum of quality related to the quantity and complexity of the support provided.

Whyville is a virtual world that frames successful completion of basic science challenges as currency. The case study evaluated support provided by cheat sites—from a list of answers (traditional cheating), to supplemental conceptual reference material, to reworded problem statements—and examined the community valuation of these practices. Some practices, such as providing supplemental conceptual reference material, which "changed the game strategy from trial and error to a more systematic and less time-consuming search" (Fields & Kafai, 2009, p. 77), were upheld by players as meeting the ethical standards of the game. It is unclear how the game developers would frame this contribution. Many developers discourage (through public statements and legal challenges) the sort of active renegotiation that these researchers have highlighted. While some developers have been known to incorporate previously unauthorized community contributions, the modifications, if adopted, are most often formally added without compensation or attribution (attribution is more common than compensation).

When recruiting participants for research studies on the efficacy of educational practices, researchers commonly seek to include individuals who have been previously

Whyville has more than 100 games and activities from checkers to music maker. Below are a few examples:

In ***Wilson City Rescue***, protect the citizens of Wilson, earn clams, and climb the ranks of the Fire Service to Battalion Chief! Fire hazards in the home, distracted drivers, and pedestrians in peril -- watch out!

Figure 7.3
Screen capture of minigame choices and description of *Wilson City Rescue* from Whyville.net.

identified in terms of national, state, and school-reported metrics as underperforming or at risk of being failed by the system in which they are being measured. However, when these individuals' learning trajectories are measured in game studies, they often demonstrate improved learning outcomes (Hayes & Gee, 2010; King, 2013; Steinkuehler & King, 2009). We also see regular descriptions like that of Elizabeth King's three-year study of 17 teenage friends who play video games together with proficiency. King examines the group through the lens of computer-supported cooperative learning (CSCL) at work research. In particular, the activities of one participant are outlined: "Bronson, a ninth grader … had been identified as 'at-risk' in his school setting and throughout the study he earned very poor grades; as a freshman in high school, he had already been labeled severely credit deficient" (King, 2013, p. 212). King continues, "He certainly does not evidence the effectiveness of his knowledge acquisition processes through test taking or writing a paper, as is the norm in formal learning environments. Instead, he evidences his skills and abilities through a more authentic assessment involving not only his individual abilities but also the collaborative efforts of his entire raid team" (p. 218). In addition to proficiency as measured within CSCL professional work practices, in order to play in the way he preferred, the participant performed nontrivial software modifications at a higher level than most nontechnical professionals in the workplace would perform on their own. In these contexts, otherwise marginalized learners are demonstrating mastery that is valued by the community.

Game-based learning research has brought to the forefront a social paradigm that moves beyond the standard structure of late-stage capitalist relationships of power and status in the United States. Participants in game communities often demonstrate community dynamics that take for granted the alternative possibility spaces within play. In game scholarship, we commonly see examples of the fluidity in teacher-learner roles; emergent social hierarchies based on demonstrated expertise (rather than age or SES); explicit recognition of the meta-game and processes of its active renegotiation, including emerging spaces of pedagogical authority; and instances where learners who have been marginalized in traditional classrooms are recognized as successful in game communities. It is through these empirical studies that we see standard relationships of power and status reorganized by participants.

Sociocultural Metrics of Success in Designing Games for Learning

Learning from a sociocultural perspective is situated within authentic social interaction. The situatedness of learning from this perspective presents a challenge for designers seeking to create learning experiences in the lab, where they are apart from a community. Like most games designed from an educator's perspective, games for learning have a limited reach, namely through use during classroom time or as a vehicle for completing homework. The learning targets for young children up to approximately age nine for structural concepts such as base 10 (e.g., counting to 10) and base 60 (e.g., telling time) arithmetic are outside our scope of interest for this chapter. What we mean when we talk about *successful reach* is authentic, and voluntary, uptake by learners. What we mean when we talk about *successful learning outcomes* is identity change driven by learner interest through social interaction that results in a contribution to the community, and what we mean when we talk about metrics of *successful learning game design* is the creation of a shared cultural space for meaningful and transformative player collaborations across the game and its concomitant community artifacts (both digital and material) in ways that are player authored and not merely designer driven. That is to say, the game becomes the seed for a community of sense making, even if only temporarily and transient. We take up each of these aspects separately.

First, a successful game is one that serves as a shared cultural space for meaningful and transformative player collaborations. There are several necessary components to transformational play, and while we highlight some fundamental facets, they are not an exhaustive list, and none are sufficient in and of themselves. Shared cultural space is a fundamental community attribute and the home of authentic assessment data. In digital games, these spaces are virtual, and, as in the case of many games discussed in this chapter, corporeal as well. Gameplay interaction (e.g., loot inventory, raiding partner history, chat logs) and forum data (e.g., comments, upvotes) are examples of output data from these shared spaces. They publicly signal a player's position within the community. The mutability of these data provides the explicit degrees of freedom for identity transformation given by the game. For designers, an a priori understanding of what identity transformation from novice to expert looks like for a community can help inform not only meaningful assessment metrics but also where and how those metrics natively reveal and conceal themselves in shared spaces. As Barab, Gresalfi, and Ingram-Goble (2010) explain:

> Designing for transformational play involves establishing academically useful and meaningfully engaging situations where learners adopt goals, have legitimate roles, and develop increasingly sophisticated relations to disciplinary concepts. They do so by experiencing and reflecting on the concepts' utility for making sense of and changing story lines in which the concept is relevant as an interpretive tool (e.g., using one's under-standing of eutrophication to interpret the source of a water-quality problem in a virtual park). In such contexts, there is a shift away from dispensing facts and transmitting particular content and toward a commitment to supporting students as they enter into conceptually illuminating situations where they develop passions and apply content understanding. (Barab, Gresalfi, & Ingram-Goble, 2010, p. 534)

Over the past decade, the developers of *Atlantis Remixed* have been iterating study and design (a.k.a. design-based research) with classrooms in more than 13 countries to better understand the affordances of transformative play in formal learning environments. The game is "not a teacher, it is a curriculum" (Center for Games and Impact, 2012, p. 3), and is only played as a group with a teacher. That teacher must first learn to master the game through customized professional development that teaches how to craft an "experience of one class in QA [that] might look very different from that of another based on the priorities of that teacher, who is the one who understands the needs of that particular classroom" (ibid.). The research on transformational play is still emerging, and it can be explored more fully through the work of scholars such as Brian Sutton-Smith, Sasha Barab, Kurt Squire, and Joshua Tanenbaum.

Second, a successful game is one that generates other artifacts, resources, and cultural creations, both digital and corporeal. In 1991, *SETI@home* was launched by the University of California, Berkeley. The game is simple to play. After downloading the software and setting parameters for interaction, the player can select various data visualizations and watch as statistics increase over time while they wait to discover whether a data packet contains evidence of extraterrestrial contact. In 2001, the game's creators wrote that their design priorities included explicitly informing participants about the out-of-game impacts their participation had in the scientific communities in which they were a part. These priorities included "how they have individually contributed to the project by providing information about potential signals they have detected and the areas of the sky they have scanned" (Korpela, Werthimer, Anderson, Cobb, & Lebofsky, 2001, p. 83). In 2002, *SETI@home* was updated and the *BOINC* (Berkeley Open Infrastructure for Network Computing) (Berkeley SETI Research Center, 2018) platform was released. The *BOINC* platform, while originally designed for *SETI@home*, allowed different versions of massively distributed computing games to be supported. One of these new games was *Rosetta@home* (which would become *Foldit*), a protein folding game released in 2005 by biochemist David Baker and colleagues from the University of Washington. Here, in addition to watching statistics change, players also watched a data visualization of an algorithm folding protein models. Player feedback to the designers included frustration at the limited actions required of the player simply to turn the game on or off. The players asked for more interactive features, and in 2008 *Foldit* was released. According to Hand, *Foldit* "not only allowed users to assist in the computation, but gives them an incentive to do so. … *Foldit* players compete, collaborate, develop strategies, accumulate game points and more to different playing levels" (Hand, 2010, p. 685). According to the *Foldit* homepage, the contributions by players in-game, in forums, and through feedback loops with scientists and game designers have resulted in the out-of-game "advance[ment of] protein science by accurately predicting the structure of a viral protein, by developing an algorithm for protein modeling, and by redesigning a protein enzyme with improved activity" (University of Washington Center for Game Science et al., 2018).

The successful community culture that emerged from *Foldit* has been cited by the National Institutes of Health as a motivating factor in the Big Data to Knowledge initiative and the December 2014 workshop "seeking to forge collaborations between biomedical researchers and games developers" (Landhuis, 2016, p. 6577). By many measures, *Foldit* is an example of successful learning game design. The game has become a platform for multiple communities to interact. These interactions have resulted in contributions of *artifacts*, *resources*, *and cultural creations* across learning communities in laboratories, health care systems, classrooms, and many other places, and all these interdependent interactions developed from the original, primarily passive, *SETI@home* gameplay and the designers' relationships with the communities they sought to serve, and still do 20 years later. From this original game community, a variety of games have emerged, and with those games, active ongoing relationships between the growing communities of designers and players. The game designers' responsiveness to changing community needs in terms of allowable inputs and outputs—within and outside the game—contributes to its continuing success.

Finally, a successful game is one that cedes control to the players, allowing a shift from designer-driven top-down representation to player-generated meaning. The tensions between the social hierarchies in traditional classroom environments and game-based learning environments curiously reflect similar tensions within the game industry and its fandom. Authority within video game worlds is a complex issue that game scholars have examined in terms of financial and legal rights and responsibilities and the ways in which these areas are seeing regular contestation by players and unpaid developers who contribute to the game world in tangible ways. In classrooms, the authority figure dispensing teaching is the older person at the front of the room; in game contexts, however, demonstrated expertise, including aspects such as contributions to the game world and to the participant communities, qualifies the participant as an expert. The game *Dota 2* (Valve Corporation, 2018) "spawned a number of emergent teaching spaces like *YouTube* videos and theorycrafting websites which are outside of [the developer]'s direct designs but which still serve as vital channels for teaching and learning. … [D]ifferent sites may use very different teaching methods (some highly didactic, some demonstrative, some interactive or based around dialogue and debate), so *where* a learner [chooses to go] can deeply influence *how* they are taught" (Holmes, 2015, p. 94, emphasis in original). This sort of catch as catch can, interest-driven learning strategy in game worlds challenges the accepted standardized norms in education hegemony, and we see recurring calls for more attention into the ways learners are seeking knowledge to satisfy their needs, which are often not met in their classrooms. Some classroom teachers are beginning to challenge "standardization" head-on not only by engaging with customizable interactive curriculums like *Atlantis Remixed* but also by learning to build games that serve the needs of their specific student communities.

The Institute of Play highlights examples for teachers seeking to design games for their community of learners. In a collection of game-based learning case studies, they describe their *Q Design Pack for Games and Learning* as "offer[ing] a framework to develop learning games … to help align game goals with learning goals … based on backward planning, which means knowing your students' learning goals" (Weitze, 2014, p. 236).

There are some notable examples of successful games for learning that were designed separate from a specific community. Perhaps the most globally recognized examples of games designed by educators for learning are the work of Katie Salen, the Center for Game Science at the University of Washington, and the lab of Constance Steinkuehler and Kurt Squire, Games+Learning+Society. Video game development engines like Gamestar Mechanic teach systems thinking and modeling by designing games (Torres, 2009) where the "kids who played the game did, in fact, develop systems thinking skills along with other important skills such as innovative design" (Shute and Ke, 2012, p. 49).

Relations to the Three Other Foundations of Game-Based Learning

Different perspectives make different facets of learning visible and invisible. In this volume, game-based learning from the fields of cognition, motivation, and emotion present various ontologies through empirical studies, including data types, collection strategies, and methods of analysis. In sociocultural approaches, cognition is a multifaceted system with the unit of study as the intact social and material activity, embedded in rather than abstracted from, real-world scenarios. The point is not so much that arrangements of knowledge in the head correspond in a complicated way to the social world outside the head but rather that they are socially organized so as to be indivisible. "Cognition" observed in everyday practice is distributed across—stretched over, not divided among—mind, body, activity, and culturally organized settings (which include other actors) (Lave, 1988, p. 1). Learning is defined as enculturation into the knowledge, skills, and dispositions valued by a community that are achieved through social interaction. Here, authentic learning assessment is demonstrated through contributions to the community.

The goals of a learning system from a sociocultural perspective are community determined. They are the values germane to the development of the culture as a whole at the time. When we examine game worlds, we find that the learner's interest in transforming their role within the community is the driving force in knowledge acquisition. Issues around motivation and persuasion are subsumed in the process of learners pushing themselves forward toward goals of interest that the game supports rather than from teachers pulling or nudging them along a trajectory that is not of authentic interest to them. Concepts such as a learner's competence, autonomy, and relatedness are likewise inseparable from the learner's position within the community. When a novice gains mastery, it is not just a feeling but also a valued contribution to the learner's community. Autonomy is evident not in "meaningful choices" but in the learner's interest driving them along the trajectory of mastery. According to Ryan and Rigby (chapter 6 in this volume), "The circumstances and environments that facilitate learning are, happily, also those that deepen enjoyment through autonomy and competence satisfactions, leading to sustained engagement." This includes those circumstances and environments that surround playing the game.

A Game Design Approach

Mixed methods combining qualitative and quantitative research practices are a "'third wave' research movement building on the idea of pragmatism. … Mixed methods data gives completeness to an analysis, resulting in a more comprehensive account of phenomena" (Steinkuehler et al., 2011, p. 222). Game-based learning research may be initiating a fourth wave in coupling mixed methods with sociocultural awareness, thereby reorienting researchers' positions to include pedagogical responsibility and explicit civic engagement. This wave rises to meet the communities of interest as equal partners in collaborative knowledge-creation practices. In *Ways of Knowing in HCI*, Gillian Hayes describes methods of action research (AR) where common goals and metrics for success are codefined with stakeholders: "Key to this type of research is that it includes the community participants as co-researchers throughout and that the result of the intervention be helpful and sustainable insofar as possible" (Hayes, 2014, abstract). While pragmatically this approach is resource intensive and generally cost prohibitive, the ethical foundation of explicitly engaging participant communities is one that is often framing game-based research.

For example, at present, Kathryn Ringland has been studying the Autcraft community across a wide range of platforms for more than three years and explains that, "The Autcraft community was created for children with autism and their allies. This community maintains a *Minecraft* virtual world in tandem with other social media platforms, including YouTube, Twitch, Twitter, Facebook, and a community-maintained website (including an administrator's blog, community forums, member profiles, and an in-browser web messenger)" (Ringland, Wolf, Boyd, Baldwin, & Hayes, 2016). Ringland collected data through "interviews [with] children and parents, participant observations, directed and non-directed forum discussions, chat logs, and digital artifacts." After being granted permission by the server's creator for the longitudinal study, Ringland entered the in-game world as a "researcher" avatar wearing a lab coat and "the researcher's presence and purpose was made clear to the community through both the *Autcraft* (Duncan, 2018) web-based forum as well as in the in-world chat. Community members were able to ask the researcher questions about the study through the forums or by visiting the researcher at an in-world 'home office.' Parents were informed of the lead researcher's presence via a parent message board and the Facebook page of the community. The lead researcher … [continues to maintain] a public website with postings of updates from the study, including any publications" (Ringland et al., 2016, p. 36). Studies like Ringland's suggest rigorous scholarship is placing greater value on various forms of knowledge sharing with study participants, and that research is moving from *designing studies of subject populations* to *co-designing studies from a place of authority recognized within a given community.*

Autcraft is an example of a game modification designed to develop prosocial behaviors for learners with autism. The community values sociality. The goal of gameplay is to support participants in developing prosocial behaviors. Over time, with regular iterative cycles based on participant interaction data, talk data, and participant caregiver feedback, the game established consistent rules between multiple platforms. The learning outcomes are evidenced through participant contribution to the game world—the ways in which participants play the game (including exploration techniques, changes to the virtual environment, and minigame completion) and participate in in-game chat and talk data across platforms. The learning outcomes sought by the community for learners are evolving, and the game's administrators are in it for the long haul, adding content in response to changes in the community. From a sociocultural perspective, the ideal game design process would include an ongoing feedback loop, a relationship between the evolving game and the evolving community learning goals.

Limitations and Implications for Designers as Community Researchers

When Lev Semyonovich Vygotsky's work *Mind in Society* was translated into English in 1978, a new generation of scholarship in the United States and United Kingdom was inspired to consider learning from a broader, more social, and more cultural context. Activity theory, and then Big-D discourse theory and New Literacies, all found deeper patterns of connection between the individual development of the learner and the communal development of the community of practice in which that learner is situated. As these interwoven lines of inquiry have progressed, not only has the scope of context of study and unit of analysis expanded but also the set of analytical tools and their use. Over the past four decades, methodologies have emerged that are well suited to examination of social interaction within game worlds. Game worlds exist in the borderland between the physical and the imagined, the game and the context in which it is played, the player and the community. In other words, the boundaries of game-based affinity spaces are messy, so their meaningful examination must include data that come from more than one source. The strength these various data and methods provide in triangulating research is not without cost. These studies often require that multiple researchers over long periods collect, clean, organize, and make sense of the data. Complex methods and management of large-scale projects are not uncommon. Take, for example, the five-year study conducted by Ito that included

> a variety of geographic sites and research methods, ranging from questionnaires, surveys, semi-structured interviews, diary studies, observation, and content analyses of media sites, profiles, videos, and other materials. Collectively, the research team conducted 659 semi-structured interviews, 28 diary studies, and focus group interviews with 67 participants in total … [in addition to] interviews informally with at least 78 individuals and [participation] in more than 50 research-related events such as conventions, summer camps, award ceremonies, and other local events. Complementing [their] interview-based strategy, [they] also clocked more than 5,194 observation hours, which were chronicled in regular field notes, and collected 10,468

> profiles on sites such as MySpace, Facebook and Neopets (among others), 15 online discussion group forums, and more than 389 videos as well as numerous materials from classroom and afterschool contexts. In addition, [their] Digital Kids Questionnaire was completed by 402 participants, with 363 responses from people under the age of 25. (Ito, 2008, p. 7)

While this project certainly represents one of the larger-scale investigations, the overall diversity and span of data sources included is customary. Sociocultural studies of digital game-based learning are data intensive and analytically intense, and therefore often resource intensive.

It is through understanding change in learning communities that we can identity patterns of proficiency development, yet the timescale of interest is generally separated into two camps, the short view (e.g., Black's one-year study) and the long view (e.g., Stevens's 10-year study). DeVane describes some of the complexity inherent in understanding changes in identity and relationships over time as "credible methods must also discern the self-social relations engendered by gradations of time. The larger debate over models of identity in the social sciences has largely been a tacit debate about whether to measure self-social processes at shorter or longer timescales" (DeVane, 2014, p. 234). His own work is a case in point. Through a multiyear study of young learners playing *Civilization 3* (Take-Two, 2018) in an afterschool program, and in particular the case of a single learner's activities signaling transformation, DeVane was able to explicate how "these acts are rooted in historical discourse norms of gender and culture, elicited by dynamic events in the social context, mediated by the shifting cooperative and competitive mechanics of game play, and sustained by [the participant's] own personal goals, interests, and patterns of participation. At the same time, [the participant's] acts link seemingly disparate social practices and involve different temporal and analytic levels of identification. The resulting identity work is the product of a skein of social practices, mediational means (game-based and otherwise), and personal trajectories, which were all embedded in different temporal layers of social processes" (DeVane, 2014, p. 233).

For those who consider longitudinal studies "essential" (King, 2010), rigorous research in the field commonly finds that "learning trajectories had to develop over time, as [learners] identified new interests, were exposed to new software tools, observed models of how those tools could be used for creative purposes, and chose their own trajectories of IT learning" (Hayes, King, & Lammers, 2008, p. 6). Rebecca Black's yearlong ethnographic study of intertextually savvy English-language learners examined "the everyday interactions and literacy-related activities of participants" in order to "gain a nuanced understanding of how language and discourse shape, and are shaped by, the social practices and context of the community" (Black, 2005, p. 120). Recognizing meaningful changes in a learner's progress then takes not only diverse data sources but also time.

Finally, it must also be acknowledged that technological progress advances at a rapid rate, so the responsiveness within the community of sociocultural game-based learning scholars must also progress. Changing technology facilitates changing forms of social interactions. Researchers have found that "[k]ey challenges involved the continually evolving nature of … gameplay as well as the complexities associated with collecting data from collective and parallel gaming practices, both triggering the need for data analysis drawing upon multiple methods" (King, 2010, p. 487). Lammers et al. state, "When Gee (2004) first conceptualised affinity spaces, social media such as Facebook, Twitter, YouTube and Tumblr did not exist. Our research indicates that social media is now an intrinsic part of participating in affinity spaces. Moreover, portals to affinity spaces are always emerging, changing and closing. As new tools and spaces are developed and gain traction, the size, scope and practices of affinity spaces will change" (Lammers et al., 2012, p. 55). Therefore, sociocultural researchers in game-based learning must consider timescales in their study designs while engaging heterogeneous data and methods in a rapidly changing technology ecology. Game-based learning research from a sociocultural approach is not for the faint of heart.

When we consider a sociocultural foundation, we begin our line of inquiry at the seams of community interactions, where place, privilege, and resource use are embedded in identity. In the United States, late-stage capitalist policies describe educational institutions as business models (Buras, 2011; Hursh, 2007; Olssen & Peters, 2005). Capitalism and pedagogy make for odd bedfellows that tend to frame learning goals in terms of competition for scarce resources. Technologies that replace human activity, from robotic manufacturing to voice-response customer service, are often seen as a magic bullet for solving perceived problems of personnel scarcity in profit-driven decision making, and this has extended to learning contexts. Compulsory institutional education systems have been prioritizing scalability, with various strategies being employed to increase the ratio of students served per teacher. Research from a sociocultural perspective, however, tends to provide insight into learning systems within and constituting meaningful human relationships.

Teaching is a political act. Designing a curriculum or developing a game with the express purpose of evoking change in a child, or an adult for that matter, is inherently political. In this volume, game-based learning is digitally augmented, which requires resources that include computers, peripherals, and often internet connectivity. Digital game designers need to consider and address these needs a priori, ideally with a clear understanding of the community the intervention is targeting. In research, study designs must account for the position of study participants in terms of access to the resources required. Squire and DeVane, for example, provided hardware, software, internet access, and a space for collaboration with the high school participants in their *Civilization 3* afterschool program. In another study, Decker and Lawley distributed RFID key fobs to university students in a study of *Press Play*. In their multiyear study of the design, development, deployment, and eventual demise of *Press Play*, they found that students requested (and were granted) access to computer labs on the university campus in order to tutor other students for free and on their own time out of a desire to increase engagement with the game (Decker & Lawley, 2013). Here, the study was focused on undergraduate academic success and retention rates for a computer science program, and, in addition, found teachers emerging from a community of students to support others. The emergence of teachers from a community of students? How do we even measure these types of learning outcomes? Quantitatively? Qualitatively? Such questions are at the leading edge of work in this domain and should be undertaken as part and parcel of the work of designing any learning intervention. Designing a game to teach should include rigorous research into the sociocultural implications for the community the intervention is targeting.

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III Design Foundations of Game-Based Learning

8 Instructional Support, Feedback, and Coaching in Game-Based Learning

James C. Lester, Randall D. Spain, Jonathan P. Rowe, and Bradford W. Mott

Introduction

Advances in game-based learning environments are introducing a broad range of opportunities for supporting student learning. The past decade has witnessed significant theoretical developments (Adams & Clark, 2014; Clark, Sengupta, Brady, Martinez-Garza, & Killingsworth, 2015; Gee, 2007; Gibson, Aldrich, & Prensky, 2007; Habgood & Ainsworth, 2011), the creation of game-based learning environments for many subjects (Adams & Clark, 2014; Halpern, Millis, & Graesser, 2012; Kebritchi, Hirumi, & Bai, 2010; Warren, Dondlinger, & Barab, 2008), and an expanding body of literature on the design and educational effectiveness of digital games (Adams & Clark, 2014; Habgood & Ainsworth, 2011; Ketelhut, Nelson, Clarke, & Dede, 2010; Meluso, Zheng, Spires, & Lester, 2012; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013).

Games have long held great promise for creating learning experiences that are both effective and engaging. Although in the past the potential of games to support learning was viewed as substantial, until recently there was little empirical evidence to support this view. Recent syntheses of the game-based learning literature have found that games can yield positive learning outcomes across a range of subjects and settings (Connolly, Boyle, MacArthur, Hainey, & Boyle 2012; Martinez-Garza, Clark, & Nelson, 2013; McClarty et al., 2012; Perrotta, Featherstone, Aston, & Houghton, 2013; Sitzmann, 2011). Furthermore, a pair of meta-analyses independently concluded that game-based learning is often more effective than traditional instructional methods with respect to learning and retention (Clark, Tanner-Smith, Killingsworth, & Bellamy, 2013; Wouters et al., 2013).

Although there is now significant evidence suggesting that games can serve as an effective medium for learning, a key problem posed by game-based learning is how to support learners most effectively. In particular, an open question in research on game-based learning environments is how to design instructional support, feedback, and coaching that are artfully integrated into core game mechanics in a manner that serves the dual functions of advancing gameplay while simultaneously promoting learning.

Instructional Support, Feedback, and Coaching in Game-Based Learning

Instructional support, feedback, and coaching serve an important role in game-based learning environments. The guidance provided by various forms of support holds the potential to promote deeper learning experiences and enable learners to focus on the most salient aspects of a learning scenario. In contrast, one can imagine game-based learning environments that operate in a pure discovery learning fashion in which learners are given no support (Kirschner, Sweller, & Clark, 2006). In these environments, learners would be expected to support their own learning experiences without any guidance, and these might yield the same types of unsatisfying outcomes as some discovery learning experiences (Mayer, 2004). Thus, embedding guidance in game-based learning holds much appeal.

A particularly compelling category of game-based learning environments that provide dynamic instructional support, feedback, and coaching is *intelligent game-based learning environments*, which integrate game technologies and intelligent tutoring systems (Lester et al., 2013). Research on intelligent game-based learning environments is investigating a broad range of functionalities for providing dynamic instructional support, feedback, and coaching that are tightly integrated into game-based learning environments (DeFalco et al., 2018; Lee, Rowe, Mott, & Lester, 2014; Lester et al., 2013; Pezzullo et al., 2017; Robison, McQuiggan, & Lester, 2009; Rowe & Lester, 2015).

Because it is hypothesized that game-based learning environments can promote learning through adaptive support, the design of intelligent game-based learning environments is guided by the premise that intelligent tutoring system functionalities can be introduced into games to provide key support mechanisms that have emerged from several decades of research on intelligent tutoring systems (Woolf, 2009). These mechanisms are often decomposed into what are termed “outer loop” mechanisms and “inner-loop” mechanisms (VanLehn, 2006).

Functionalities in the “outer loop” of an intelligent tutoring system are responsible for selecting the tasks that students will perform. For intelligent game-based learning environments, task selection could be used to determine which episode of a game a student will interact with, which level of a game a student will play, or which problem-solving scenario within a level a student might be given. As with “outer loops” in intelligent tutoring systems, a variety of pedagogies might be implemented, and an intelligent game-based learning environment can select from a predefined set of these or perhaps dynamically generate them using procedural content-generation techniques (Shaker, Togelius, & Nelson, 2016).

Intelligent game-based learning environments can also implement intelligent tutoring systems’ “inner loop.” Functionalities in the “inner loop” of intelligent tutoring systems typically focus on support that is centered on smaller granularities of subject matter and span shorter intervals of time (VanLehn, 2006). Intelligent tutoring system “inner-loop” supports include providing minimal feedback on a fine-grained problem-solving action, providing feedback that is specific to particular conceptual or problem-solving errors, providing hints on potential upcoming problem-solving actions, assessing students' knowledge, and conducting a review of a student's proposed solution. Intelligent game-based learning environments can provide analogous families of support for students. For example, they can use nonplayer characters or pedagogical agents (Johnson & Lester, 2016) to provide minimal or error-specific feedback on a student's actions in the game or hints related to a student's upcoming quest; they can conduct stealth assessment (Min et al., 2015; Min, Frankosky, et al., 2017; Shute, 2011) to provide a formative assessment of the student's competencies as evidenced through gameplay; and they can perform an after-action review (Brown, 2011) to review a student's recent gameplay experience.

This chapter explores instructional tactics that can be implemented in intelligent game-based learning environments to support learning with a focus on inner-loop functionalities. Connections between instructional strategies and theories of learning are used to highlight how support can be designed to help learners select relevant information in the learning environment, organize information into coherent mental representations, and provide learners with hints and support during task performance to guide learning.

What Do We Know about Instructional Support, Feedback, and Coaching in Game-Based Learning?

In this section, we review relevant research literature regarding the effectiveness of instructional support, feedback, and coaching in game-based learning environments. To foreshadow the discussion, we note that research in this area is still in its infancy. Although many claims have been made about the benefit of game-based learning environments, empirical evidence regarding their effectiveness is fragmented and riddled with methodological limitations. Mayer and Johnson (2010) described three general methods researchers have used to evaluate learning outcomes with games. The *cognitive consequences* method is used to investigate whether playing a game improves a specific cognitive skill (i.e., what do players learn from playing the game?). With the *media comparison* method, researchers compare whether people learn better with games or conventional media. A third method researchers use is to compare the learning outcomes of students who receive different versions of the same game (i.e., which type of feedback is most beneficial for learning; see Mayer & Johnson, 2010). This third approach, referred to as the *value-added approach*, is the most relevant for evaluating the impact on learning outcomes of instructional support and feedback in games (Mayer & Johnson, 2010). In the following sections, we review research that has used each of these approaches and discuss how the results can be used to improve student outcomes in game-based learning environments.

Supporting Learning in Game-Based Environments through Feedback

It is well established that feedback is important for learning in game-based learning environments (Azevedo & Bernard, 1995; Mayer, 2014). The purpose of feedback is to help learners evaluate their progress and performance, identify knowledge gaps, and repair faulty knowledge (Johnson & Priest, 2014). Ultimately, providing learners with feedback can be an effective method of guiding them to achieve a deeper understanding of the subject matter.

In a recent review of the feedback and gaming literature, Johnson, Bailey, and Van Buskirk (2017) identified four general ways in which feedback can be instantiated in game-based learning environments and provided a review of their effectiveness. Specifically, the authors found feedback can vary according to (1) the content of the feedback message, (2) the timing of the feedback message, (3) the modality in which feedback is presented, and (4) whether feedback is adapted based on learner aptitude or characteristics. They also proposed that content feedback be further classified according to whether the feedback message is outcome oriented or process oriented. *Outcome-oriented feedback* provides learners with information about their current level of performance or the correctness of their response (Johnson et al., 2017). Examples of outcome feedback include knowledge of results ("your answer is correct"), knowledge of correct results ("the correct answer is D"), error flagging ("the last part of your answer is incorrect"), and environmental feedback (a student's answer results in a character receiving an award). *Process-oriented feedback* provides learners with explanatory information about the processes or strategy used to reach the correct answer (Johnson et al., 2017). Its purpose is to provide the learner with information that can be used to close the gap between his or her current level of understanding or performance and the level of performance required to meet the objective in the game. Examples of process-oriented feedback include informational prompts and hints that guide students toward the correct answer, topic-specific feedback, and error-sensitive feedback that provides information related to why an answer is correct or incorrect. As noted by Johnson et al., outcome and process feedback are not mutually exclusive: feedback statements can include both forms of content (Johnson et al., 2017).

What do we know about the effectiveness of feedback content in game-based learning environments? In general, empirical evidence suggests that process-oriented feedback is superior to outcome-oriented feedback (e.g., minimal feedback) for helping learners develop a deeper understanding of instructional material. The benefits of process-oriented feedback are evident in near transfer tasks and tests of knowledge retention. For example, Mayer and Johnson (2010) explored the benefits of explanatory feedback in an arcade-style educational game designed to teach students how to solve problems about electrical circuits. In the game, students gained or lost points based on their ability to correctly solve circuitry problems. When students submitted a correct answer, they received a “correct” tone and several points. When they submitted an incorrect answer, they received an “incorrect” tone and lost points from their score. Students who played the standard version of the game received minimal feedback (through the tones and points). Students who played the explanatory version of the game received minimal feedback as well as process-oriented feedback that explained the correct answer. The last level of the game served as an embedded transfer test and required students to use their knowledge of electrical circuitry to solve a complex circuitry problem. Results showed that students in the explanatory feedback condition outperformed participants in the outcome-oriented feedback condition during gameplay ($d = 1.31$) and on the embedded transfer task ($d = .68$). The authors concluded that providing direct guidance in the form of explanatory feedback helped students develop a deeper understanding of the material than providing minimal guidance through corrective feedback alone.

Using a value-added approach, Moreno and Mayer (2005) also found benefits from providing learners with explanatory feedback in a multimedia-style game. In their study, college students learned about botany while playing an interactive game called *Design-A-Plant* (Lester, Stone, & Stelling, 1999). During gameplay, students traveled to five alien planets, learned about plant parts and weather conditions, and learned how to design a plant that could flourish in different environmental conditions (figure 8.1). Students were supported during the game by a pedagogical agent, Herman the Bug, who offered individualized advice and feedback on the relationship between plant features and weather conditions. Students were randomly assigned to receive either minimal feedback on the correctness of their answer during game play or explanatory feedback about why a certain plant design would survive or perish in the planet’s environment. After finishing the game, students completed a retention test to assess their understanding of basic factual information about botany and a problem-solving test, which required students to apply the principles they learned in the game. Results showed that students who received explanatory feedback scored higher on near ($d = .75$) and far ($d = 1.68$) transfer problem-solving tasks than students who received corrective feedback only, and they produced fewer incorrect answers during gameplay. These results suggest that providing learners with explanatory feedback in game-based multimedia environments can promote deep, meaningful learning.

More recently, researchers have investigated the generalizability of providing process-related feedback in more immersive game-based training environments. For example, Billings (2012) used a value-added approach to investigate the effect of providing learners with different levels of feedback specificity during a game-based training exercise designed to teach search-and-rescue procedures. The training exercise required participants to navigate in a virtual environment and search buildings for different items while following a set of procedures outlined in the learning objectives. The learning objectives included procedures for entering and exiting buildings, clearing buildings, and communicating with headquarters. Four feedback conditions were

Figure 8.1
Screenshot of *Design-A-Plant* learning environment.

compared: nonadaptive detailed feedback, nonadaptive general feedback, adaptive top-down feedback, and adaptive bottom-up feedback. Each condition corresponded to different levels of feedback specificity. In the nonadaptive detailed condition, participants received feedback about which learning objectives they failed and how to correctly perform them after each mission (e.g., "Before entering or tagging a building, you should walk around the entire building to make sure it is not already tagged"). In the nonadaptive general condition, participants only received general feedback statements about the learning objectives they forgot to apply during the training mission (i.e., "Remember to apply the procedures for entering and exiting a building"). In the adaptive bottom-up feedback condition, students began the training missions by receiving detailed feedback about the errors they committed. After demonstrating increased mastery of the learning objectives, the feedback statements changed from detailed to general. Conversely, in the adaptive top-down condition, participants started with general feedback and then faded to statements that were more detailed if learning objectives were not being met. Billings (2012) postulated that providing students with adaptive bottom-up feedback would produce better learning outcomes than the nonadaptive strategies, because of the advantages associated with personalized instruction. Billings also posited that detailed feedback would be better at supporting knowledge integration because it facilitated learning at the subtask level rather than providing support at an overall conceptual level of the task. Results generally supported these hypotheses. Participants in the adaptive bottom-up and detailed conditions achieved higher levels of performance more quickly than participants in the top-down or general feedback conditions. That is, providing detailed feedback facilitated learning that was more efficient compared to providing general feedback. Further results showed that participants in the general condition performed significantly worse than those in the adaptive bottom-up condition. Billings concluded that detailed feedback seemed to be the best option for designing feedback in simulation-based training environments and that the results support theories such as cognitive load theory. Specifically, the benefits of providing learners with specific rather than general feedback appeared to stem from telling learners directly what procedure they needed to follow rather than their having to recall this information themselves. This reduced cognitive load and made learning more efficient.

Serge, Priest, Durlach, and Johnson (2013) conducted a follow-up experiment to further examine feedback specificity properties in game-based learning environments. Participants in this experiment performed the same search-and-rescue training and transfer task as in Billings's (2012) study described earlier and received the same types of feedback (general, specific, adaptive top-down, adaptive bottom-up). In addition, Serge et al. allowed trainees in the general feedback condition to review the training manual at the end of each mission. They included this option to determine whether individuals who took advantage of this opportunity (i.e., reviewing detailed procedures for performing the task) performed similarly to those who received detailed feedback. Overall, results showed that participants who received detailed feedback learned how to perform the task more quickly than those under other conditions. In addition, participants in the general feedback condition who reviewed the training manual between missions performed just as well on the task as trainees who received detailed feedback. However, individuals who chose not to review the training manual performed as poorly as those in the control condition who did not receive any feedback. These results lend support for the powerful benefits of providing detailed feedback to learners through inner loop functionalities in game-based training environments.

In sum, the results of these experiments show that process-oriented feedback improves learning outcomes for novice learners when compared to outcome-oriented feedback in game-based learning environments (Johnson et al., 2017). One explanation for these observed benefits is that providing learners with error-specific information or explanative information reduces extraneous processing and helps learners more easily identify the source of their misunderstandings. In turn, learners have more cognitive resources to dedicate to essential processing, which helps facilitate deeper learning (Johnson & Priest, 2014; Mayer, 2009). These results suggest that intelligent game-based learning environments that offer detailed or error-specific feedback through inner-loop functions might more effectively support learning.

What do we know about the effectiveness of feedback timing in game-based learning environments? In addition to feedback content, feedback timing can also influence learning in game-based environments. A major question facing designers of game-based learning environments is whether to present feedback to learners immediately after they make a mistake or after a delay. As noted by Johnson et al. (2017), guidance for this question is rather mixed because of conflicting theories and empirical findings. Proponents of immediate feedback suggest that providing feedback immediately after errors prevents errors from being encoded during the acquisition phase of learning (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Shute, 2008). The benefits of immediate feedback have been demonstrated in cognitive tutors and step-based intelligent tutoring systems for two decades (Anderson, Corbett, Koedinger, & Pelletier, 1995; Corbett & Anderson, 1995). In these environments, results show a strong learning effect associated with students who receive immediate feedback on step-based learning errors. Advocates for delayed feedback adhere to the interference-preservation hypothesis proposed by Kulhavy and Anderson (1972), which asserts that errors interfere with encoding corrective information when feedback is delivered immediately and that people make fewer preservation errors if feedback is delayed.

A review of the feedback literature suggests that the question of when to provide feedback partly depends on the intended goal of learning. Immediate feedback seems to be more beneficial during the acquisition phase of learning (Anderson, Magill, & Sekiya, 2001; Corbett & Anderson, 1995; Dihoff, Brosvic, Epstein, & Cook, 2004), but delayed feedback may be better for promoting transfer. This general assumption has received some empirical support. For instance, Schmidt, Young, Swinnen, and Shapiro (1989) found that providing feedback immediately after a trial produced higher performance during practice but led to worse performance during training transfer. Conversely, delayed feedback resulted in lower performance during the acquisition phase of training but better performance during a transfer phase.

Although one may imagine the benefits of both immediate and delayed feedback in game-based environments, relatively little research has systematically evaluated feedback-timing policies in game-based learning. One notable exception is a study by Johnson, Priest, Glerum, and Serge (2013) that examined three feedback-timing policies for training procedural skills in a game-based environment. Participants were trained to perform the same search-and-rescue task described in the study by Serge et al. (2013), but received feedback at one of three timing schedules: immediately after an error (immediate condition), at a logical stopping point in the scenario (chunked condition), or at the end of the scenario (delayed). Although the results did not reveal any statistically significant differences between the timing conditions, data trends showed that participants in the immediate feedback condition performed slightly better than those in the delayed or chunked condition. Importantly, the authors found that the delayed feedback groups reported higher levels of cognitive load, while the chunked and immediate groups reported lower levels of cognitive load. These findings led the authors to suggest that immediate feedback may help reduce extraneous cognitive load in game-based training environments but that more research is needed in this area (Johnson et al., 2013).

Van Buskirk (2011) found a similar benefit from providing immediate feedback in a simulation-based task designed to train military call-for-fire procedures. During the simulation, participants scanned simulated terrain for enemy targets, identified targets, determined which threats to neutralize based on a set of prioritization rules, and then called in artillery fire to the position of the threat. The author manipulated the type of feedback participants received (outcome vs. process feedback), when they received it (immediate vs. delayed feedback), and the modality in which the message was presented (visual vs. auditory feedback). An important contribution of this study was that the author hypothesized that the effectiveness of the feedback delivery parameters would depend on the processing demands imposed by the task. More specifically, Van Buskirk hypothesized that because learners were performing a visual-spatial task, the relative effectiveness of feedback content (process vs. outcome) would depend on when and how it was presented. She hypothesized that outcome feedback would be more effective if it was presented immediately after an error, whereas process feedback would be more effective if the message was delayed. She also hypothesized auditory feedback that was presented immediately would be most effective because the message delivery modality would not suffer from the same level of processing interference as a message presented in the visual modality. Results showed that participants who received immediate, auditory, process feedback outperformed those receiving all other types of feedback on the target prioritization portion of the task. Although the results of the study did not support the hypothesized interaction, the author noted that a confounding factor caused by exposure to environmental feedback in the simulation may have attenuated the differences between the immediate and delayed feedback. These results highlight the importance of considering the processing demands of the feedback message and task when designing feedback timing policies.

More recently, Landsberg, Bailey, Van Buskirk, Gonzalez-Holland, and Johnson (2016) found benefits from providing learners with delayed feedback in a similar type of simulation-based training system. This experiment investigated the relationship of feedback timing, feedback granularity, and environmental feedback in a simulation testbed designed to train individuals to estimate a ship's angle relative to their own line of sight. The task required participants to make accurate and timely decisions about the orientation of their ship relative to a simulated ship viewed through a periscope. Participants received feedback either immediately after each trial (immediate feedback condition) or after every 15 trials (delayed feedback condition). Results showed that participants in the delayed feedback condition made decisions more quickly than individuals in the immediate feedback condition. Furthermore, participants in the delayed feedback condition also viewed feedback messages for longer than participants in the immediate condition did. Landsberg et al. (2016) concluded that by delaying feedback, participants had a chance to more actively process the feedback message, which led to faster decision making and response times on subsequent trials.

Based on the results presented here, it may be that one of the primary benefits of delaying feedback is to provide students with a chance to reason about their own errors and self-correct before receiving feedback. Mathan and Koedinger (2005) found support for this type of reasoning in two studies that examined two feedback-timing policies in an intelligent tutoring system designed to teach novices how to write formulas in a spreadsheet. Although the study was not performed in a game-based environment, the results have implications for the design of game-based learning environments. Specifically, Mathan and Koedinger reasoned that the debate regarding when to give feedback should not be based on a simple policy of feedback timing alone but rather on the model of desired performance. If the model of desired performance includes promoting metacognitive skills for error detection and correction, then learners should be allowed to exercise these skills before receiving feedback. If the model of desired performance mimics that of an expert, then immediate feedback should be provided. These researchers found that participants who were allowed to make reasonable errors, self-evaluate, and correct their errors prior to receiving feedback performed better on tests of problem solving, conceptual understanding, transfer, and retention compared to learners who received immediate feedback.

As demonstrated in these studies, feedback during the learning process is clearly beneficial to individuals. Detailed process feedback seems to provide the most benefits to learners (Billings, 2012; Johnson et al., 2013; Serge et al., 2013). However, guidance on when to deliver feedback is mixed. Many decisions about whether to delay feedback or provide it immediately seem to depend on moderating factors, such as the type of task or the intended learning objectives (e.g., promoting retention vs. promoting transfer). Of the studies we reviewed, none focused on narrative-centered learning environments or story-driven game-based learning environments, which have become increasingly prominent. Narrative-centered learning environments can serve as an ideal “laboratory” for investigating how to deliver feedback compared to other types of game-based environments because of their story-driven design and tendency to utilize first- or third-person perspectives through gameplay. These environments offer an interesting opportunity for integrating feedback within a believable world. Storyline characters could provide detailed feedback to learners during gameplay, and changes to the story line could provide a form of realistic environmental feedback (Johnson et al., 2017; Johnson & Lester, 2016). Understanding when and how to give feedback in these types of games, as well as other forms of game-based learning environments, continues to be an important question that needs to be answered with empirical research.

Support and Coaching in Game-Based Learning

Like feedback, support and coaching in game-based learning environments can take many forms. Some game-based environments include cues for guiding learners' attention and information selection, some include features that provide support for organizing and recognizing important information, and others provide support for reflection and integration of knowledge. Although it is generally accepted that including support is necessary to prevent learners from floundering (Mayer, 2004), empirical research on the effectiveness of different approaches and types of support in game-based environments is still somewhat sparse. Several notable examples, however, have addressed this question using a value-added, cognitive consequences, or media comparison approach. We describe several of these studies.

Supporting information selection in game-based learning environments One of the challenges of situating learning in game-based environments is that these environments offer a greater number of possible paths and objectives to explore compared to traditional forms of instruction (e.g., PowerPoint slides). The higher level of interactivity and the story-driven design of some environments may impact the ways that learners select, organize, and integrate information compared to static forms of multimedia instruction (Adams, Mayer, McNamara, Koenig, & Wainess, 2012; Mayer, 2009). To alleviate these demands, some researchers have incorporated attentional cues within games to draw users' attention toward characters or critical elements that need to be explored. For instance, in *Crystal Island* (Lester et al., 2014; Lester, Rowe, & Mott, 2013), a game-based learning environment for middle school microbiology education, visual cues such as highlighting are added to books and other articles that learners can interact with (figure 8.2). These cues are meant to direct learners' attention toward important task-relevant cues while at the same time reducing extraneous load.

Similar forms of attentional support have been implemented in other inquiry-based learning games. For instance, Nelson, Kim, Foshee, and Slack (2014) used a value-added approach to investigate the efficacy of including visual cues in a narrative-centered virtual environment designed to assess scientific inquiry. The virtual environment involved gathering evidence and testing hypotheses regarding why a new flock of sheep was not thriving at a new farm. Learners played the role of a local scientist who could interact with virtual characters, explore the local landscape, and use a set of virtual tools to collect data from sheep scattered around the farm. The study included two test conditions: (1) a visual signaling condition in which 3D symbols (i.e., visual cues) hovered above characters and objects (e.g., sheep) with which learners could interact, and (2) a nonvisual signaling condition. To indicate that an object had been viewed, the status and color of each visual signal changed once a learner interacted with it. The authors hypothesized that by including visual cues, learners would be more likely to interact with relevant objects and experience decreased cognitive load. Study results

Figure 8.2
Screenshot of *Crystal Island* game-based learning environment.

supported these hypotheses. Specifically, participants in the visual signaling condition reported lower levels of cognitive load in a postgame survey. Furthermore, trace data from the game revealed that participants in the visual signaling condition interacted with key objects more often ($d = .34$), collected more measurements from sheep ($d = .51$), and took more notes in the electronic clipboard provided in the game ($d = .48$) than participants in the nonsignaling condition. These results show that the signaling principle, which states that people learn better when the design of interactive instruction includes visual or auditory cues that highlight the organization of essential material to be learned, is applicable to game-based learning environments (Mayer, 2009). Applied to intelligent game-based learning environments, these results suggest that one important function of the inner loop is to highlight important game elements or interactive objects. Providing this form of attentional support could reduce a learner's extraneous processing and free working-memory resources to create a more engaging and meaningful learning experience.

Supporting knowledge organization In addition to facilitating the appropriate selection of relevant objects in game-based learning, support can also be seamlessly embedded in game-based learning environments to help learners mentally organize selected information into coherent mental representations (Mayer, 2009). Examples include embedding into gaming environments concept graphs, graphic organizers, notebooks, and checklists that students can use to record key pieces of information or

① Patient's Symptoms

Symptom A	Symptom B
Pain	Stomach Cramps

Symptom C	Symptom D
Vomiting	No entry

② Test Results

	I have tested:	The results showed:
Object A	Egg	Not contaminated
Object B	Orange	Not contaminated
Object C	Cheese	Not contaminated
Object D	Water	Not contaminated
Object E	No entry	No entry
Object F	No entry	No entry

③ Possible Explanations

	Likelihood:	Because:
Anthrax	Unlikely	Characteristics don't match
Botulism	No entry	No entry
Ebola	No entry	No entry
Influenza	Unlikely	Characteristics don't match
Salmonellosis	Possible	No entry
Smallpox	Very unlikely	Characteristics don't match

④ Final Diagnosis

Disease	No entry
Source	No entry
Treatment	No entry

Figure 8.3

Diagnosis worksheet in *Crystal Island*.

self-reflect on what they currently know in regard to the problem they are trying to solve. Results of several studies exemplify how these types of cognitive tools can promote learning gains and interest in game-based learning environments (Shores, Rowe, & Lester, 2011).

For instance, Nietfeld, Shores, and Hoffman (2014) examined whether a structured note-taking tool embedded in a narrative-centered learning environment could effectively scaffold students' knowledge-organization processes and promote learning outcomes. Embedded in *Crystal Island* (Rowe, Shores, Mott, & Lester, 2011), the cognitive tool was a virtual diagnosis worksheet that learners could use to list patient symptoms, make notes, select likely causes, and provide a final diagnosis as they tried to solve a mystery about what caused an illness outbreak on a virtual island (figure 8.3). Using a sample of 130 middle school students, Nietfeld et al. (2014) found that students who used the virtual worksheet more frequently reported higher levels of interest, were more engaged, and showed higher learning gains than students who did not use this scaffolding. The authors summarized these results by stating how critical it is for students to use in-game cognitive tools to assist in off-loading and organizing information pertinent for successful performance in these environments.

Similar types of cognitive tools have been implemented in other interactive learning environments. For instance, *BioWorld*, an intelligent tutoring environment that trains medical practitioners on diagnostic reasoning across an array of simulated exercises, uses embedded cognitive tools to help students externalize and evaluate their reasoning processes as they diagnose patient cases and illnesses (Lajoie, 2009). These tools are designed to support monitoring processes and provide help-seeking resources commonly used during medical diagnostic events (Lajoie, 2009). One such tool embedded in the environment is termed the "evidence palette," as it provides a notebook interface to record information deemed important for supporting a diagnosis. McCurdy, Naismith, and Lajoie (2010) found that experts and novices used the tool differently, with experts collecting more evidence during the investigation phase of the game. Additional studies have found that tool usage is an important predictor of problem-solving performance in inquiry-based learning environments (Liu et al., 2009).

Graphical organizers and concept matrices are another set of cognitive tools frequently found in game-based learning environments. These instructional scaffolds can be used to help learners self-test and self-reflect on their current state of knowledge (Rowe, Lobene, Mott, & Lester, 2013). *Crystal Island* includes concept matrices that students can use to reinforce and regulate their understanding of microbiology principles. Preliminary findings of student usage activities have suggested that students' concept matrix performance is predictive of posttest knowledge scores, suggesting that this form of cognitive support plays an important role in helping students learn important scientific concepts (Min, Rowe, Mott, & Lester, 2013). In applications such as *Betty's Brain*, students use concept maps to represent their understanding of earth science topics such as food chains, photosynthesis, or waste cycles. Students receive feedback on the correctness of their concept linkages through their interactions with the virtual agent in the platform. This support was found to improve students' own reflective behaviors (Jeong & Biswas, 2008).

Empirical evidence also suggests that embedding subproblems (e.g., miniquests) within a game-based learning environment can support more efficient learning compared to asking learners to solve a more complex activity (Shores, Hoffman, Nietfeld, & Lester, 2012). As a form of cognitive support, these more proximal goals have the potential to scaffold the learning process by breaking down learning objectives into cognitively manageable units, providing useful, frequent feedback, and maintaining motivation and the novelty of the experience (Shores et al., 2012).

Taken together, these results show the promise of including cognitive tools in game-based environments to support learning outcomes. Cognitive tools can be used to offload and organize information that is pertinent to successful performance in the environment. Perhaps more importantly, cognitive tools can help prompt self-regulatory behaviors among learners. Self-regulation has been identified as an important component that supports learning in game-based environments. Learners with high self-regulatory skills are more likely to set goals, check their progress against these goals, and adjust their strategy when their current level of performance is not aligned with their goals (Azevedo, Behnagh, Duffy, Harley, & Trevors, 2012). Cognitive tools can also serve as an indirect method for reminding learners to engage in specific tasks and facilitate metacognitive and self-regulatory learning processes (Lester, Mott, Robison, Rowe, & Shores, 2013; Roll, Wiese, Long, Aleven, & Koedinger, 2014).

Supporting knowledge integration and task performance In addition to directing a learner's attention and supporting knowledge organization, support can be used in game-based learning environments to provide explicit guidance to learners as they perform a task. Such support can be instantiated in the form of hints, prompts, pumps, and elicitation statements designed to provide learners with reminders about the goals of the task, hints about how to solve a problem, or prompts to elaborate an answer, self-explain a concept, or self-reflect on their current level of understanding (Aleven & Koedinger, 2002; Lester, Mott, et al., 2013; Roll et al., 2014). In traditional step-based intelligent tutoring systems, such as those designed to teach mathematics or physics, students can request hints as they work toward solving a problem. The first hint may offer a "nudge" to remind students about a concept they should apply. The second hint may be more directive. The final hint—called the bottom-out hint—may provide the answer. The tutor may also provide hints proactively. Intelligent game-based learning environments that incorporate intelligent tutoring capabilities offer similar forms of support, and there is growing evidence that these interventions can have a positive impact on learning.

For instance, *BiLAT*, a game-based instructional system designed to teach cultural awareness and bilateral negotiation skills, has been shown to improve the negotiation skills of novice negotiators during meetings (Kim et al., 2009). *BiLAT* requires that learners interact with virtual characters (e.g., a local doctor) in a situated story line to achieve a particular outcome (e.g., move the local clinic). Prior to engaging in negotiations, learners complete an initial research and preparation phase, in which they gather information about the characters they will interact with and learn culturally appropriate negotiation tactics. After this initial phase, learners are placed in narrative-driven scenarios where they must successfully negotiate with virtual characters to achieve their mission goals. Learners select speech acts or actions from a menu, and the virtual characters react to these selections. The menu serves as a scaffold for novice users who may not be able to generate these actions on their own. During negotiation meetings, the system provides students with hints regarding appropriate actions. Hints are triggered according to the phase of the meeting (e.g., greeting and rapport phase, business phase), the list of available actions, and the learning objective. Hints start by offering general information in regard to the learning objective (e.g., begin with a sign of respect) and then progress to more detailed and corrective hints and suggestions if the trainee does not demonstrate competence during the negotiation (e.g., "take off your sunglasses"). The coach also offers feedback based on a student's most recent action. In an evaluation of *BiLAT*, Kim et al. (2009) found that novice negotiators who trained with *BiLAT* over a relatively short period increased their negotiation skills as measured through pretest and posttest learning gains on a situational judgment test.

Nelson (2007) investigated the impact of an individualized guidance system that was embedded in an educational multiuser virtual environment called River City. The guidance system was designed to help students solve scientific inquiry problems. River City depicted a late nineteenth-century town that included shops, a library, an elementary school, and other institutions. Upon entering the town, students could interact with virtual characters, digital objects, and avatars of other students. Students were required to explore different sections of town and develop hypotheses about why residents were ill. Students could view objects in the virtual world, such as historical photos, books, and charts, and could use interactive tools. They could also interact with virtual characters to learn more about the town and potential causes of illness. The guidance system compiled a cumulative model of student interactions with these objects and used this information to provide students with personalized support and guidance. For instance, when a student initially interacted with an object, the system would provide a default set of questions or prompts that would provide guidance for the student. If the student returned to the same object after interacting with other objects, it would provide more tailored guidance and reflection-oriented prompts based on the student's previous actions. In a sample of approximately 290 middle school students, Nelson (2007) tested the impacts of three levels of support within the game—no guidance, extensive guidance, and moderate guidance—on learning outcomes. Students in the extensive guidance condition could view three guidance messages per predefined object, while participants in the moderate guidance condition had access to only one guidance message per object. Initial results showed that students who had access to individualized guidance did not score better on measures of learning than students in the no guidance condition. The authors found that although students had access to guidance, they viewed on average 12 to 15 messages out of a total of more than 200 in the moderate condition and 600 in the extensive condition. However, post hoc analyses showed a significant linear relationship between frequency of guidance usage and test score gains, suggesting that individuals who were more frequent users of the guidance learned more from the game.

Additional examples of support and coaching in game-based learning environments can be found in several studies that have used *Crystal Island*. McQuiggan, Rowe, Lee, and Lester (2008) used a media comparison approach to investigate whether story-driven content included in *Crystal Island* supported student learning. The authors compared two versions of *Crystal Island* against a traditional form of multimedia-based instruction. The full version of *Crystal Island* included a rich story line about patient illness, complex character interrelationships, and interactions. The minimal version contained a trimmed-down version of the storyline that was minimal enough to support only the problem-solving scenario. Results showed that students in the full and minimal conditions achieved learning gains, but they did not learn as much as students who received traditional multimedia instruction covering the same curricular material. However, further analyses revealed that students who interacted with *Crystal Island* reported high levels of self-efficacy, presence, and interest in the topic compared to those in the traditional condition. These findings shed light on the motivational benefits of narrative-centered learning.

In a later study, Rowe et al. (2011) used a revised version of *Crystal Island* and found improved learning gains compared to the study by McQuiggan et al. (2008). Specifically, learners showed higher levels of in-game performance, presence, and situational interest in the game. The improved learning gains were believed to be associated with several key additions that resulted in a more immersive and supportive learning experience. These additions included an expanded diagnosis worksheet that learners could use to record, organize, and integrate information, a tighter coupling between the narrative and microbiology curriculum, and a new activity in which students actively labeled parts of cells. These items were meant to provide learners with more scaffolding during the game. While additional research is needed to determine the benefits of these features systematically, the results show a promising trend toward improving student learning and student affect in game-based learning.

Support Offered through Pedagogical Agents

Pedagogical agents are another form of scaffolding and support found in many game-based learning environments. A growing body of research has shown that pedagogical agents can benefit learning experiences (Schroeder, Adesope, & Gilbert, 2013). Pedagogical agents are interactive computer characters that "cohabitate learning environments with students to create rich, face-to-face, learning interactions" (Johnson & Lester, 2016, p. 26). They are often used in inner-loop functions of intelligent game-based learning environments to mimic many of the same activities performed by human tutors: they evaluate a learner's understanding through interactions, ask questions, offer encouragement, and give feedback. They can also present relevant information and hints, offer examples, and interpret student responses (Johnson, Rickel, Stiles, & Munro, 1998). Examples of pedagogical agents include Steve, a lifelike agent designed to help students learn equipment maintenance and device troubleshooting procedures, and Herman the Bug, a cartoon-like agent designed to help students learn botanical anatomy. Steve can demonstrate skills to students, answer student questions, and give advice if the students run into difficulties (Rickel & Johnson, 1999). Herman the Bug watches students as they build plants, offering them assistance and problem-solving advice (Elliott, Rickel, & Lester, 1999). Pedagogical agents are particularly effective when they offer support, coaching, and guidance that encourage students to engage in generative or active processing (Moreno & Mayer, 2005).

Virtual learning companions are a special class of pedagogical agents that take on the persona of a knowledgable peer and are designed to share the learning experience with the student (Kim & Baylor, 2006; Ryokai, Vaucelle, & Cassell, 2003). Unlike virtual tutors, these agents do not serve a teaching role in the learning environment. Instead, they are meant to experience learning tasks alongside the learner and serve as near peers. These companions can support learning through social modeling (Ryokai et al., 2003), and they have the ability to improve self-efficacy by reducing frustration (Buffum, Boyer, Wiebe, Mott, & Lester, 2015), boosting confidence and empathizing with the student (Woolf, Arroyo, Cooper, Burleson, & Muldner, 2010). Thus, these agents can offer social-emotional support, which can in turn improve student motivation in game-based learning environments.

Support Offered through Teachable Agents

Teachable agents are interactive computer characters that are designed to offer support in game-based learning environments. Students teach the teachable agent about a subject and assess the agent's knowledge by asking it to solve problems or answer questions (Biswas et al., 2005). The teachable agent uses artificial intelligence techniques to answer questions. The feedback the student receives by observing the teachable agent's performance helps them discover gaps in the agent's knowledge. Students can use this feedback to provide remedial tutoring to the agent, similar to what a real human tutor does with a struggling student. Teachable agents capitalize on the experience of learning-by-teaching and in doing so allow students to engage in three critical activities that promote learning: knowledge structuring (students acting as tutors organize their own knowledge), motivation (students acting as tutors take responsibility for learning the material), and reflection (students acting as tutors reflect on how well their ideas were understood and used by the tutee) (Biswas et al., 2005; Chin et al., 2010). Studies have shown that tutors and teachers often engage in these actions during and after the teaching process in order to better prepare for future learning sessions (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001).

Perhaps one of the most well-proven and extensively researched teachable agents is *Betty's Brain*, which was developed by researchers at Vanderbilt University and used in middle schools to help students learn about earth science (Leelawong & Biswas, 2008). In *Betty's Brain*, the agent has no initial knowledge and is taught about a subject through peer tutoring. Students teach Betty about a particular topic (such as a river ecosystem) using concept map representations. As students teach Betty, they can ask her questions to see how much she has understood. Once taught, Betty applies qualitative reasoning techniques to answer questions related to the subject. Students can also ask Betty to take a quiz. Mr. Davis, a mentor agent within the learning environment, grades the quiz and provides hints to help students debug and make corrections in Betty's concept map. This cycle of teaching and assessing continues until the virtual tutee performs up to standards.

The idea of learning-by-teaching is both intuitively appealing and one that has garnered support in the research literature. Research on the effectiveness of teachable agents indicates that students who tutor teachable agents exhibit higher levels of motivation and learning compared to students who passively receive training from an artificial agent (Leelawong & Biswas, 2008). For instance, Leelawong and Biswas (2008) conducted a study comparing two versions of a teachable agent system—one baseline version and a second version that included self-regulated learning principles and provided metacognitive hints to students—to a condition in which students were taught by a pedagogical agent. The findings indicated that students in the two learning-by-teaching conditions learned more than students in the pedagogical agent condition and that these benefits persisted in a transfer study. Specifically, students who learned via learning-by-teaching made greater effort and had better success in learning material on their own compared to students who received instruction. These results highlight the benefit of supporting generative processing through teachable agents.

What Are the Implications for the Design of Game-Based Learning?

The research discussed in this chapter has several implications for the design of game-based learning. Instructional support such as attentional cues, cognitive tools, hints, prompts, and feedback offer significant promise for helping learners select relevant objects and information in the learning environment, organize this information into coherent mental structures, and facilitate meaningful learning, while at the same time off-loading working memory and promoting engagement.

Empirical evidence suggests that attentional cueing and visual signaling are two ways to help learners recognize and select essential material in game-based learning environments (Mayer, 2010). These cues help to direct learners' attention toward relevant objects and locations in a learning environment and reduce extraneous cognitive load. This advice follows the signaling principle of multimedia instruction (Mayer, 2009). Cognitive tools are another critical form of support in game-based learning, particularly those that focus on inquiry and problem solving. Cognitive tools are used to replicate the externalization of knowledge by providing tools and processes that are inherently used by an expert when solving a problem (Lajoie, 2009). They assist learners in solving problems and organizing relevant information, with the intended benefits of reducing cognitive load and scaffolding the problem-solving process. Evidence shows that learners who use cognitive tools often produce better scores in learning games than those who do not take advantage of this support (Chin et al., 2010; Lajoie, 2009; Nietfeld et al., 2014). Furthermore, research shows that prompts and hints that encourage learners to self-reflect and engage in generative processing, and feedback messages that provide principle-based explanations for errors, are particularly effective for promoting learning in game-based learning environments. These messages can prompt students to engage in metacognitive processing that is important for learning, such as elaboration, self-explanation, and self-checking (Aleven, Stahl, Schworm, Fischer, &

Wallace, 2003; Azevedo & Hadwin, 2005; Roll et al., 2014). These forms of support may be especially important in narrative-centered learning environments where students participate in story-based educational experiences and must demonstrate reasoning and other higher-order analytical thinking and reasoning skills to achieve the goals of the game (Lester, Mott, et al., 2013).

When implementing feedback, coaching, and support, designers should be cautious not to overload a learner's already limited processing resources and capacity. Designers should also take into account a learner's evolving level of knowledge as they deliver and provide support. Ideally, the level of support offered by the inner loop of a game-based learning environment should be tailored to a learner's evolving competence. For instance, a novice student might begin an exercise with a high level of coaching and support, but over time the level of support should decrease as the student's level of mastery increases, until the student is performing the task on his or her own, which is the process of *fading* (Wood & Wood, 1999). One of the challenges for game designers is to determine what type of support to offer and when to make it available to learners. In addition, research also shows that using pedagogical agents and teachable agents as a mechanism for offering support and promoting reflection and self-explanation can promote learning while at the same time providing learners with educational and social-emotional support. These instructional features can be tightly intertwined in game mechanics to keep the learner on task, promote reflection, and reduce frustration and confusion.

What Are the Limitations of Current Research, and What Are Some Implications for Future Research?

While there is growing evidence suggesting that game-based learning environments can serve as an effective medium for learning, a key problem posed by game-based learning is how to support learners most effectively. Feedback, support, and coaching can be implemented in a variety of ways. Identifying the optimal methods, modalities, and timing of delivery is critical for supporting learners in game-based learning environments. There is a significant need to investigate how learners use cognitive tools in game-based learning environments. Exploring game trace log data and using eye-tracking measures are promising directions for identifying effective learner behaviors (Taub et al., 2017). There is also a lack of research examining how cognitive tools could be dynamically tailored to meet individual needs (Rowe et al., 2013). Research on the expertise reversal effect and cognitive load theory suggests that scaffolding should be gradually removed as learners become more proficient in a topic (Kalyuga, 2007). If scaffolding remains at a fixed level, it could cause extraneous load for learners who are more experienced. Following this theory, one could reasonably predict that too much structure and support could result in diminished learning gains for knowledgeable students. Fading support can be implemented in a variety of ways. For example, in the case of a diagnosis worksheet, learners could be provided with minimal structure and be required to fill in sections with important information in the form of freeform text rather than selecting multiple-choice options. Alternatively, learners could be required to specify how the worksheet should be designed and then complete the form themselves (Rowe et al., 2013).

Another limitation in the literature is that most studies measure retention and transfer immediately after a student completes a learning task. In doing so, there is no way to determine the lasting impact of the intervention on learning. As noted in the feedback literature, approaches that promote immediate retention and transfer may not foster delayed transfer and vice versa. Future research should address this by examining performance on delayed retention or transfer tasks as well as immediate tasks. This would provide evidence on potential moderating factors associated with certain forms of support and feedback.

In line with these suggestions, another promising avenue for future research is to explore boundary conditions on the effectiveness of feedback, support, and coaching. A guiding question for this line of research is: does the effectiveness of certain forms of support depend on the type of game or other learner-based factors (e.g., gender, expertise, personal interests)? Empirical evidence suggests that males and females use cognitive tools and pedagogical agents differently (Nietfeld et al., 2014). Pezzullo et al. (2017) found that boys experienced higher mental demand compared to girls when they interacted with a virtual agent that was embedded within the story line of a game-based learning environment. These gender effects held even after controlling for prior knowledge and video game experience.

Furthermore, with advancements in artificial intelligence, multimodal sensors, and learning analytics, there are a multitude of emerging technologies that could be used to investigate the impact of feedback, support, and coaching on learning outcomes. For example, we are seeing the appearance of multimodal models of goal recognition that can accurately recognize the goals that students are pursuing when interacting with game-based learning environments (Baikadi, Rowe, Mott, & Lester, 2014; Ha, Rowe, Mott, & Lester, 2014; Min, Ha, Rowe, Mott, & Lester, 2014; Min, Mott, et al., 2017; Min, Mott, Rowe, Liu, & Lester, 2016), approaches for using multichannel data to assess in-game performance during gameplay (Taub et al., 2017), and student modeling techniques that utilize facial expression recognition (Sawyer, Smith, Rowe, Azevedo, & Lester, 2017). Perhaps even more enticing is the prospect of dynamically customizing gameplay experiences with advanced computational models utilizing deep reinforcement learning (Wang, Rowe, Min, Mott, & Lester, 2017) and techniques for balancing learning and engagement with multiobjective reinforcement learning (Sawyer, Rowe, & Lester, 2017). These customized experiences can be created with both outer-loop and inner-loop functionalities of intelligent game-based environments to provide learners with challenging scenarios while at the same time offering tailored support for individual learners. These are exciting times for game-based learning research, and the next few years are likely to see the appearance of the next generation of theoretically driven, empirically based approaches to support, feedback, and coaching.

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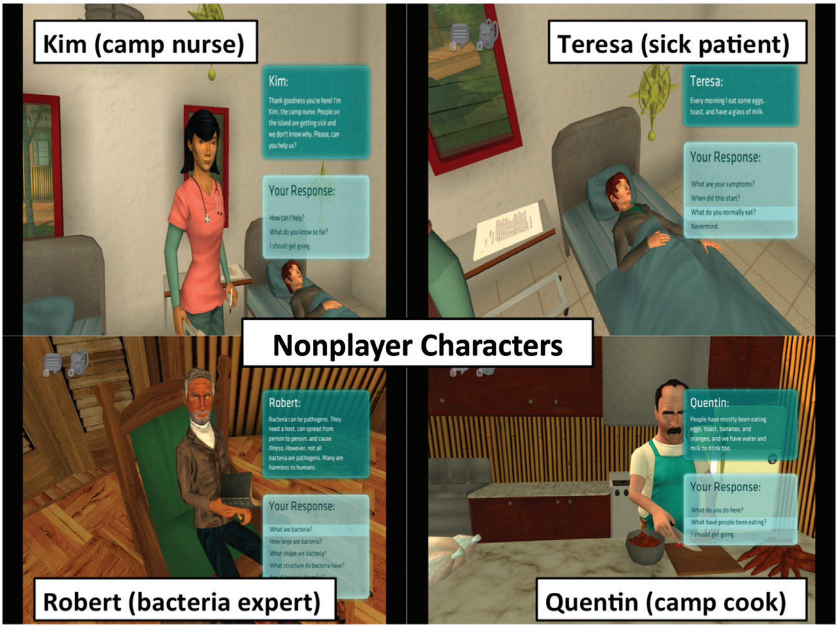
9 Self-Regulation and Reflection during Game-Based Learning

Michelle Taub, Roger Azevedo, Amanda E. Bradbury, and Nicholas V. Mudrick

Introduction

Research has shown that students often fail to remain engaged and motivated as they learn a challenging topic, such as math, biology, or physics (Azevedo, 2014). Thus, game-based learning (GBL) has been implemented in classrooms and computer-based environments to ensure that students maintain high levels of enjoyment and motivation during learning of complex topics, while still monitoring and regulating their cognitive and metacognitive processes (Plass, Homer, & Kinzer, 2015; Plass, Homer, Mayer, & Kinzer, chapter 1 in this volume). However, when students learn via GBL, it is important that they not only enjoy the experience and maintain high motivational states (e.g., interest, task value, intrinsic motivation) but also acquire the knowledge the game set out to teach them (Mayer & Johnson, 2010; Plass et al., 2015). The design of games includes aesthetically pleasing elements, such as the environment itself, objects to interact with in the game (e.g., books with animations, a scanner that accurately mimics what a scanner would look like in real life), and nonplayer characters (NPCs) that contain human-like features (e.g., voice, gestures, facial expressions, movement). Therefore, although these elements make it enjoyable to play the game, researchers must ensure that students continue to acquire knowledge from the game by using these system features to acquire information and not only explore them. To do so, these games should foster self-regulation and self-reflection, such that students are able to monitor and control their actions to ensure they are learning and problem solving efficiently with GBL environments.

When students engage in GBL, there are different types of cognitive, affective, metacognitive, and motivational self-regulatory and reflective processes they can engage in to ensure they are learning efficiently. As an example, take a student who plays the game *Crystal Island* to solve the mystery of what illness has spread and impacted inhabitants of the island (Rowe, Shores, Mott, & Lester, 2011; Taub et al., 2017). First, the student must gather contextual information from the nonplayer character Kim, the camp



Kim:

Thank goodness you're here! I'm Kim, the camp nurse. People on the island are getting sick and we don't know why. Please, can you help us?

Your Response:

How can I help?
What do you know so far?
I should get going.

Teresa:

Every morning I eat some eggs, toast, and have a glass of milk.

Your Response:

What are your symptoms?
When did this start?
What do you normally eat?
Nevermind.

Robert:

Bacteria can be pathogens. They need a host, can spread from person to person, and cause illness. However, not all bacteria are pathogens. Many are harmless to humans.

Your Response:

What are bacteria?
How large are bacteria?
What shape are bacteria?
What structure do bacteria have?

Quentin:

People have mostly been eating eggs, toast, bananas, and oranges, and we have water and milk to drink too.

Your Response:

What do you do here?
What have people been eating?
I should get going.

Figure 9.1
Screenshots of nonplayer characters in *Crystal Island*.

nurse (figure 9.1). She informs the student of their task and the activities they need to engage in to solve the mystery. From this, the student can engage in *planning* to set out how they will gather the clues they need to solve the mystery and which locations they will travel to and in what order. They can also activate their prior knowledge to determine what they might already know about microbiology, and specifically about certain illnesses. Next, the student must engage in knowledge acquisition and information gathering. They must interact with sick patients to determine their symptoms as well as the food they typically eat, and interact with experts on viruses and bacteria to learn more about their behavior, structure, and function (figure 9.1). They can also read books, research papers, and posters to learn about viruses and bacteria, and different types of viral and bacterial illnesses, as well as complete concept matrices, which assess their understanding of the text (figure 9.2).

The student can also interview the camp cook to determine the types of food he had recently made (figure 9.1). To monitor all this gathered information, the student uses a tool called a diagnosis worksheet (figure 9.3), which can be used to mark down reported symptoms and the likelihood of certain illnesses based on the symptoms that are associated with each illness, which they learned from reading books, research papers, and poster contents, and talking with the experts. Then, based on all

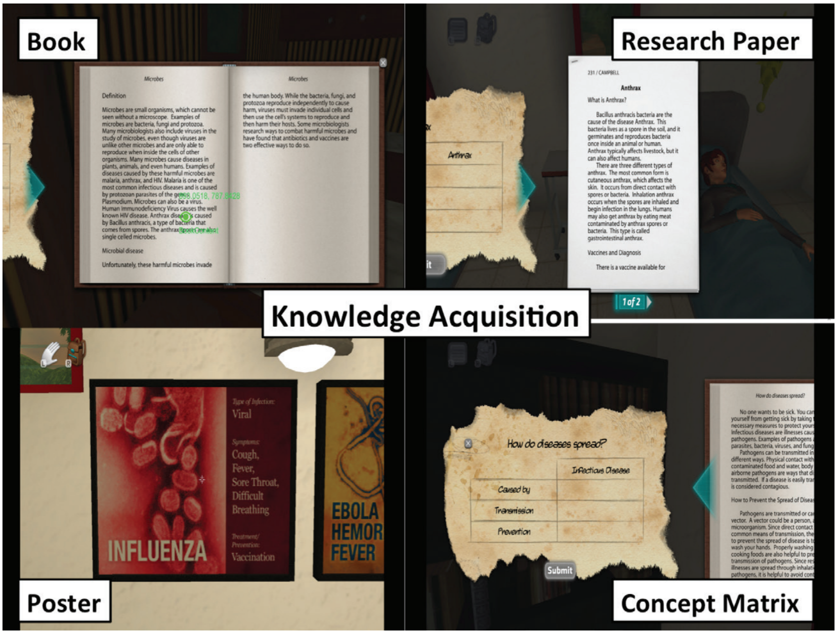
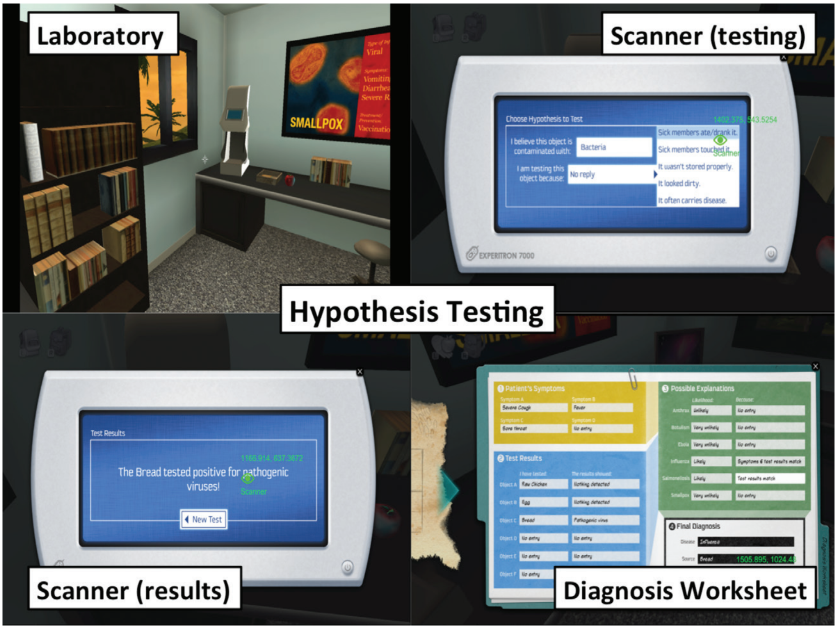


Figure 9.2
Screenshots of knowledge acquisition activities afforded by *Crystal Island*.

this acquired information, they must make inferences and form hypotheses about the possible cause of the patients' illness and what food items might be transmitting it.

Once the student has formed these hypotheses, they can test food items as the transmission source of the illness (figure 9.3). If the student is an efficient learner, they will infer that the food items that are the possible transmission source are those that the sick patients reported eating. To test food items, the student navigates to the laboratory and uses the scanner, which requires that they indicate which pathogenic substance they are testing for. A virus or a bacterium are the two possible correct options (which can be inferred from the text content); however, carcinogens and mutagens will also be choices, and the student must metacognitively evaluate that these options are not relevant to any materials they have read. The student must also specify why they are testing the food item, where asserting that sick members ate or drank it would be the correct option; however, there are also irrelevant options for the student to choose from, and the student must make this metacognitive judgment to select the correct option. Once the scanner indicates that the food item tests positive for pathogenic substances, the student has correctly identified the transmission source of the illness and must then decipher that a positive result for pathogenic, and not nonpathogenic, substances will lead them to the correct diagnosis.



Choose Hypothesis to Test

I believe this object is contaminated with: Bacteria

I am testing this object because: No reply

Sick members ate/drank it.
Sick members touched it.
It wasn't stored properly.
It looked dirty.
It often carries disease.

Test Results

The Bread tested positive for pathogenic viruses!

New Test

Figure 9.3
Screenshots of hypothesis testing and scientific reasoning activities in *Crystal Island*.

To submit a final diagnosis, the student must complete their diagnosis worksheet, which they should be using to monitor their progress throughout gameplay. The student uses the worksheet to fill out a final diagnosis, including the illness, transmission source, and treatment plan (figure 9.3), where the treatment plan must be deciphered from reading the text content and talking to the experts on viruses and bacteria. When the student makes a final diagnosis, they submit the worksheet to Kim, the camp nurse, and if she evaluates the diagnosis as correct, the student has completed the game and solved the mystery correctly. If the diagnosis is incorrect, the student must revisit their hypotheses by reading additional material and testing additional food items in order to make a correct diagnosis. Thus, it is evident that students are required to engage in several self-regulation and reflection processes during GBL.

The goal of this chapter is to discuss self-regulation and reflection during GBL, including what has already been done investigating the role of these processes on GBL and where we are going with this research. Specifically, our chapter focuses on the role of cognitive, affective, metacognitive (defined as a reflective process in this chapter), and motivational processes on GBL. First, we provide an overview of GBL research, including what recent meta-analyses have reported, and what theories of GBL focus on for designing educational games. We then discuss research that has investigated self-regulation during GBL, followed by a discussion on research that has investigated reflection during GBL. Following this, we discuss future directions, including issues with how we operationalize key constructs when assessing GBL (e.g., self-explanation, reflection, engagement), and the importance of doing so to design scaffolding for GBL environments.

Game-Based Learning: Overview

Based on the assumption that game-based learning environments (GBLEs) are more engaging and motivating than conventional instructional methods (e.g., PowerPoint, classroom instruction), researchers have designed many different GBLEs to foster learning, problem solving, and conceptual understanding for different domains (e.g., math, computer science, or biology), topics (e.g., microbiology or Newtonian physics), and age groups (e.g., elementary, secondary, or university students). Although some meta-analyses have not supported this assumption (see Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013), several others have found them to be significantly more effective than conventional instructional methods in fostering knowledge acquisition (see Clark, Tanner-Smith, & Killingsworth, 2016; Mayer, 2014a). For example, Mayer (2014a) compared game-based learning to learning with other forms of instruction and found that the median effect size for using GBLEs to foster learning was $d=0.12$ when compared to other computer-based learning environments, $d=0.53$ when compared to traditional paper-based instruction, and $d=0.63$ compared to classroom-based instruction. Mayer (2014a) also identified that GBLEs can be more effective for some specific content domains than for others. For example, GBLEs designed to foster science and second-language learning achieved effect sizes of $d=0.69$ and $d=0.96$, respectively, but there were no effects for math or language arts. Furthermore, GBLEs were found to differentially influence learning outcomes for different age groups, with different effect sizes for elementary school students ($d=0.34$), secondary school students ($d=0.58$), and college students ($d=0.74$) (Mayer, 2014a). Therefore, research has identified that GBLEs can foster learning for different age groups and different content domains, but more research is still needed regarding how and why GBLEs can foster learning.

Clark et al. (2016) conducted a meta-analysis where they began examining which specific GBL components can foster learning outcomes most effectively. The authors examined the impact of general design characteristics (e.g., scaffolding and feedback, including pedagogical agents [PAs]), types of game mechanics used, the presence of complex visual components or a detailed narrative, and the quality of the research conducted on cognitive learning outcomes (e.g., learning strategy use, knowledge acquisition). Additionally, the authors included the moderators of game duration (i.e., how long students played the game), the presence of nongame instruction in game conditions, and player groupings (i.e., if students played alone vs. in groups). Results from their analyses revealed that the effect size for cognitive learning outcomes was $g=0.35$, relative to a comparison to conventional instructional approaches (95% CI [0.20, 0.51], $\tau^2 = 0.29$). The authors went further and specified which specific components of GBLEs can foster or hinder cognitive learning outcomes. Their results suggested that the inclusion of scaffolding and feedback within GBLEs facilitated increased learning outcomes better than the inclusion of intelligent PAs or adapting game experiences to the students' individual needs (e.g., interest, content). Furthermore, their results suggested that the inclusion of detailed narratives or rich visual components within a GBLE may deleteriously impact students' learning. Specifically, Clark et al. (2016) identified that deeply contextualizing the learning content within a narrative may distract students' attention away from the content by giving unnecessary seductive details or by providing goals other than learning the content (see Mayer & Johnson, 2010). Therefore, these results suggest that not including highly detailed story lines in a game may facilitate better learning outcomes. Additionally, the results from Clark et al. (2016) identified that learning outcomes are greatest when students interact with the GBLE over multiple sessions, as results indicated that interacting with a GBLE for one session did not outperform the traditional comparisons. Lastly, results indicated that students interacting with GBLEs alone did better than students who interacted with GBLEs in groups. The results from the Clark et al. (2016) meta-analysis provide initial findings regarding the specific components within GBLEs that can foster cognitive learning outcomes. However, a substantial amount of research is needed to further identify features within GBLEs that promote learning the most effectively.

Although substantial evidence exists regarding the ability of GBLEs to foster learning, researchers have been calling for approaches that are more theoretically grounded to identify *why* they are effective (Mayer, 2015; Plass et al., 2015; Qian & Clark, 2016). Researchers have traditionally grounded their investigations of the effectiveness of GBL within frameworks of motivation and engagement (Mayer, 2014a). However, this research has been criticized for its lack of theoretical explanations regarding these ill-defined and difficult-to-measure constructs, such as engagement, motivation, or flow, along with empirically questionable approaches and inappropriate analytical techniques (Azevedo, 2015; Bradbury, Taub, & Azevedo, 2017; Graesser, 2017). Much of the literature lacks theoretical bases, and many researchers are now arguing that the design of GBLEs does not align with theories of how students learn (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Mayer, 2015; Tsai, Huang, Hou, Hsu, & Chiou, 2016; Virk, Clark, & Sengupta, 2015). Because of these general criticisms, researchers have begun to move from broader theoretical frameworks encompassing general constructs (e.g., engagement, motivation, flow) to more detailed approaches to specify underlying design components contributing to GBL effectiveness (see Mayer, 2015; Plass et al., 2015).

For example, the model of game-based learning by Plass et al. (2015) suggests that designing successful GBLEs results in the inclusion of features that facilitate the interplay between cognitive, affective, motivational, and sociocultural constructs. Cognitively, the authors suggest that successful learning with GBLEs is a result of the construction of a coherent mental model (see Mayer, 2014b) and is based on features designed to reduce cognitive load; assist in the selection, organization, and integration of the learning content; and provide scaffolding and relevant feedback. Motivationally, the model stresses the inclusion of features designed to facilitate enjoyment and interest. However, the authors also note that the literature (despite motivation being the guiding framework of much of the research on GBL) does not offer design suggestions for components that can facilitate intrinsic motivation, take into account achievement goal orientation, or differentiate between situational and individual interest. On an affective level, the model suggests including features designed to acknowledge students' emotions, beliefs, and attitudes. Specifically, Plass et al. (2015) emphasize that the emotional design of embedded game components (narrative, musical score, etc.) can facilitate the experience of positive emotions (e.g., joy), which in turn influence learning outcomes. Lastly, the model indicates the importance of investigating the interplay between the cognitive, affective, and motivational components that are based in sociocultural features. The authors argue that learning is socially constructed and motivated, and therefore GBL should be viewed within this context. The model proposes including features designed to increase personal agency and social enculturation, such as leaderboards that provide information regarding group change (as opposed to isolated, personalized feedback). Furthermore, the model stresses features designed to facilitate social interaction (chat logs between groups of players, shared tasks with a common goal, etc.). Therefore, this model emphasizes that learning with GBLEs cannot be explained solely by their assumed engaging and motivational properties and is instead a combination of cognitive (Mayer, chapter 4 in this volume), affective (Loderer, Pekrun, & Plass, chapter 5 in this volume), motivational (Ryan & Rigby, chapter 6 in this volume), and social (Steinkuehler & Tsaasan, chapter 7 in this volume) components. In sum, despite overarching criticisms regarding GBLE design lacking theoretical grounding, GBL researchers have now begun to adopt more educationally relevant and theoretically justifiable approaches to designing GBLEs (see Plass, Homer, Mayer, & Kinzer, chapter 1 in this volume) and investigating their effectiveness, such as theories of self-regulation and reflection, which we discuss in the next section.

Self-Regulation and Reflection

Self-regulation is shown when students are actively and accurately monitoring and controlling their actions and behaviors in a learning situation (Winne & Azevedo, 2014). According to theories of self-regulation (Pintrich, 2000; Winne & Hadwin, 1998, 2008; Zimmerman & Schunk, 2001), students effectively self-regulate by engaging in processes related to planning, monitoring, and strategizing through a series of phases that are not sequential (e.g., monitoring and strategizing can occur simultaneously). There are many types of self-regulation processes, such as cognitive, affective, metacognitive, and motivational (CAMM) (Azevedo, Mudrick, Taub, & Bradbury, 2019; Azevedo, Taub, & Mudrick, 2018), all of which can impact students' self-regulation and performance in different ways. One specific aspect of self-regulation involves reflecting on one's actions and subsequent performance on tasks and subtasks. This can allow making adjustments to future behaviors (Winne & Hadwin, 1998, 2008), which we define as reflection. We distinguish reflection from self-regulation to highlight the key processes that students need to use for effective GBL. Specifically, not only is it important for students to self-regulate during GBL, they must also reflect on how they self-regulated and how they can improve their previous use of self-regulated learning (SRL) strategies in the future. We discuss both these behaviors in the subsections that follow.

Self-Regulation in Game-Based Learning Environments

Many studies have investigated the use of self-regulation during GBL and have found that self-regulation does improve overall learning (Clark et al., 2016; Mayer, 2014a, 2019). Studies that have investigated self-regulation during GBL have investigated how students use SRL strategies during learning with GBLEs, focusing predominantly on students' use of cognitive (Mayer, chapter 4 in this volume), metacognitive, and motivational (Ryan & Rigby, chapter 6 in this volume) strategies during learning. For example, Ke (2008) compared cognitive math skills, motivational learning, and metacognitive awareness between game-based learning and conventional learning (i.e., paper and pencil) and found that learning with games led to higher motivation, but not higher cognitive math performance or metacognitive awareness, compared to conventional methods. In another study, Sabourin, Shores, Mott, and Lester (2013) used machine learning to predict middle school students' use of SRL behaviors during gameplay with *Crystal Island*. First, they classified students as low, medium, or high SRL based on status reports during the game. Then they compared students' learning gains and found that both high- and medium-SRL groups had significantly higher learning gains than the low-SRL group. Additionally, their results revealed that high-SRL students read significantly more posters than low-SRL students did and tested fewer items than both medium- and low-SRL students. Finally, they used machine learning to predict in-game behaviors, where they included pregame characteristics (e.g., demographic data, pretest score, and responses to self-reported questionnaires) and in-game behavior characteristics (e.g., how players used in-game resources, how many goals they completed, and the degree to which they engaged in off-task behaviors), for a total of 49 features to train four types of models. They then divided the learning session into four segments to assess the models' accuracy in predicting performance at different time points. Their results revealed that all four models could predict performance, but they concluded that decision trees and logistic regression models were the best predictive models (Sabourin et al., 2013).These authors used the level of SRL both as a grouping variable (based on their reflective statements) and as a predictor variable to determine how students used SRL strategies during GBL and how these behaviors impacted students' performance.

In a third study, Nietfeld, Shores, and Hoffmann (2014) compared self-regulation, cognitive performance, and motivational factors by gender as middle school students played *Crystal Island*. They found that use of self-regulatory strategies was positively associated with performance. Specifically, their results revealed that students who used strategies that were more cognitive and who displayed a lower metacognitive monitoring bias had a higher game-score performance. Motivationally, their results revealed that students with higher situational interest and self-efficacy had higher game-score performance. With respect to gender, their results revealed that males engaged in cognitive strategy use more often than females; however, when they controlled for the amount of time reported playing games, this effect was no longer significant. Moreover, there were no significant differences in motivation variables based on gender; however, science self-efficacy significantly predicted game-score performance for males only. Therefore, these results reveal the impact of both self-regulation and gender on GBL.

Snow et al. (2016) investigated college students' gameplay with *i-START-2*, a game-based intelligent tutoring system that teaches students strategies for reading comprehension. There are multiple phases of *i-START-2*; however, the focus of this study was on the practice phase, where students could engage in various practice games in which they could generate self-explanation texts after being prompted to do so. When playing these games, if students performed below a certain threshold, they were transitioned to coached practice, where they were given specific feedback on their performance. Overall, results revealed that after students transitioned back from the coached practice, they performed significantly better on their self-explanations. Therefore, this game was able to improve students' self-regulation and metacognitive awareness while they learned to use text comprehension strategies.

Lastly, Taub et al. (2017) used multilevel modeling to assess undergraduate students' knowledge acquisition and monitoring behaviors during gameplay with *Crystal Island*. To do so, they assessed students' instances of reading books and completing the associated assessment with each book, which asked questions on the book's content by using a concept matrix. They also examined students' proportions of eye fixations on the books and matrices during each instance of reading a book, and how these actions impacted their performance on the concept matrices (i.e., number of attempts). Their results revealed that students who read fewer books in total but read each book more frequently and had low proportions of fixations on the books and concept matrices made the fewest attempts at answering the concept matrix questions correctly (i.e., greater performance). These results demonstrate that students who were strategic readers, in the sense that they monitored which specific sections of the book were necessary to answer the questions correctly, showed the highest performance, as opposed to students who read through all book content and then moved to the concept matrix. Thus, these results reveal how Taub et al. (2017) used a nontraditional statistical technique with multichannel data to investigate students' SRL via knowledge acquisition and metacognitive monitoring during GBL.

Recently, there has been a shift toward assessing the impact of students' emotions during GBL (Loderer et al., chapter 5 in this volume; Novak & Johnson, 2012). Sabourin and Lester (2014) investigated results from a series of studies involving middle school students playing *Crystal Island*, where they compared students' self-reported emotions during learning. Their results revealed that positive affective states (being focused, curiosity) were positively correlated with learning gain, while negative affective states (confusion, frustration) were negatively correlated with learning gain. When they related emotions to motivation, they found that positive affective states were positively correlated with motivational factors such as interest, effort, and value, while negative affective states were negatively correlated with these motivational factors. Additionally, they investigated the influence of affect on in-game behaviors related to inquiry skills, problem solving, and off-task behaviors, where results also showed the beneficial impact of positive affect on these behaviors. Thus, their results revealed that positive affect can positively influence motivation, in-game behaviors, and overall performance during GBL.

A study conducted by Andres et al. (2015) investigated students playing *Physics Playground* and how their emotions and action sequences related to their performance. They classified two sets of sequences: (1) experimenting activities, and (2) behaviors that remained unresolved. They related those types of sequences with emotions and found that there were two types of sequences of experimenting behaviors that were correlated with confusion associated with less understanding of key concepts. Moreover, there was one sequence related to unresolved behaviors that was correlated with boredom, in which the activities that had been enacted to that point were correct but students did not fully complete them. Therefore, this study revealed the relationship between emotions and action sequences during GBL.

Yeh, Lai, and Lin (2016) categorized emotions based on their valence, which was positive or negative; their activation level, which was high or low; and their focus, which was based on either promotion or prevention. They assessed the impact of students' emotions on their creativity during GBL by using a game-based evaluation system. Results revealed that being happy or elated (positive valence, high activation, and promotion focused) led to increased levels of creativity, while being angry or frustrated (negative valence, high activation, and promotion focused) led to decreased levels of creativity, thereby demonstrating the relationship between emotions and subsequent behaviors during GBL.

Finally, Bradbury, Taub, and Azevedo (2017) investigated the impact of levels of agency and emotions on students' proportional learning gain during learning with *Crystal Island*. Their results revealed that students who had partial agency, which limited them to a set navigation path through the game and required them to interact with all objects (e.g., read all books, talk to all NPCs), also produced the highest proportional learning gain scores compared to students who had full agency, where they had no restrictions and were free to interact with any object in any location, or students with no agency, who did not play the game but watched an expert play and narrate all his actions. In addition, the results revealed significant positive correlations between proportional learning gain and anger, fear, confusion, and frustration in the partial agency condition, revealing that higher scores on these emotions related to greater proportional learning gain scores. Furthermore, anger was found to be a significant predictor of proportional learning gain for students in the partial agency condition. Therefore, once again we see the relationship between emotions and learning gain during GBL. However, the results of Bradbury et al. (2017) revealed the positive impact of negative emotions and learning, showing that at times negative emotions can have a positive influence on learning as well (see also D'Mello, Lehman, Pekrun, & Graesser, 2014).

Based on these studies, there is much research investigating learning gains and performance during GBL, and on students' use of cognitive, metacognitive, and motivational processes during learning. There has been an increase in research investigating the impact of affective states and emotions on GBL; however, more work is needed to pinpoint why, and in what situations, negative affective states can be beneficial for students. Findings were mixed regarding the relation between negative affective states and learning in GBL, whereas positive affective states were favored or were not correlated with learning gain (Bradbury et al., 2017). In addition, there are fewer studies investigating self-regulation and affect; thus, future research should aim at investigating affect during GBL from a self-regulatory perspective focusing on emotion regulation. Furthermore, when defining self-regulation, there does seem to be consensus on an operational definition (stating that students are playing an active role in their learning and problem solving), which allows researchers to compare results across different studies. Most studies did find favorable results for self-regulation during learning, which supports the need to continue fostering this.

In addition to these studies, researchers have focused on students' reflection, and how students engage in reflection strategies, during GBL. We view reflection as a metacognitive process, as reflection requires higher-order thinking (as described in the following subsection). However, as opposed to self-regulation, research on self-reflection is less clear, with less of a consensus on its operational definition and methods for measuring and fostering it. In the next subsection, we discuss how researchers have defined and investigated reflection during GBL.

Self-Reflection in Game-Based Learning Environments

Numerous researchers have illuminated the importance of metacognition for accurate and effective regulation of learning processes (Davis, 2003; Flavell, 1979; Harteveld, Guimarães, Mayer, & Bidarra, 2007; Mayer & Johnson, 2010; Schunk & Greene, 2018; Tarricone, 2011; Winne & Azevedo, 2014), especially during GBL (Fiorella & Mayer, 2012; Kim, Park, & Baek, 2009; Lee & Chen, 2009; Moreno & Mayer, 2005). For instance, to navigate a game environment effectively, students must enact several metacognitive processes, such as monitoring, planning, and selecting effective learning strategies. Pintrich (2000) broadly defined metacognition as the ability to direct and regulate cognitive, motivational, and problem-solving processes toward a specific goal. Additionally, metacognition can be divided into two major areas: metacognitive awareness and regulation of cognition (Ifenthaler, 2012). Metacognitive awareness involves an understanding of oneself (e.g., am I good with math? what is my prior knowledge?) along with knowledge of cognitive strategies (e.g., what strategies do I know? how do I effectively use these strategies?), tasks (e.g., have I performed similar tasks?), and contexts (e.g., do I need to rely on NPCs to support my learning with these types of games?). Regulation of cognition involves taking control of self (e.g., activating prior knowledge to facilitate learning with a game), others (e.g., engaging in help seeking by asking an NPC for additional information during GBL), task (e.g., using additional instructional resources on the web to solve a problem posed in a GBLE), and context (e.g., engaging in cognitive reappraisal to regulate my confusion as I implicitly deduce physics principles during GBL) during learning by deploying skills such as planning and monitoring, as well as cognitive strategies such as rereading or making inferences (Ifenthaler, 2012; Pintrich, 2000). Reflection is a metacognitive process linking metacognitive awareness with regulation of cognition (e.g., assessing how well I regulated my level of confusion while deducing physics principles). More specifically, when students reflect, they link understandings of their own metacognitive processes with the regulation of these processes (Ifenthaler, 2012).

Reflective thinking involves critical thinking and is essential in complex learning situations such as GBLEs. It is active, intentional, and involves an understanding of one's own learning processes (Lin, Hmelo, Kinzer, & Secules, 1999; Vrugte et al., 2015). Furthermore, it fast tracks the integration of new concepts, strengthens current knowledge structures, and increases accessibility of these structures (Vrugte et al., 2015). Additionally, Ke (2008) identified reflection as being critical for knowledge construction and positive learning outcomes in GBLEs; however, Ke also identified GBLEs as lacking essential reflection scaffolds. For instance, GBLEs are often fast paced and do not allow critical reflection without providing explicit reflection prompts (Harteveld et al., 2007). Several GBLEs have integrated reflection prompts with promising results, so there is little doubt as to their benefit; however, there is still much debate regarding the methods in which reflection is prompted (Fiorella

& Mayer, 2012; Kim et al., 2009; Lee et al., 2009; Mayer & Johnson, 2010; Vrugte et al., 2015).

Reflection has been recognized as being important to learning, with a long line of researchers encouraging learners to reflect using metacognitive strategies such as planning and monitoring (Brown, Bransford, Ferrara, & Campione, 1983; Davis, 2003; Flavell, 1979; Pintrich, 2000; Tarricone, 2011). These metacognitive skills are essential for successfully regulating one's learning and are critical to lifelong learning; however, many students have difficulty reflecting in meaningful ways (Lin et al., 1999). For instance, GBLEs require a high degree of metacognitive skill, such as the ability to plan, monitor the progress of that plan, and adapt strategies based on changing game scenarios. For this reason, many students require scaffolding to reflect effectively during GBL (Kim et al., 2009). Seeing this deficit, researchers have developed embedded reflection prompts in GBLEs and have investigated their impact on students' learning outcomes (Fiorella & Mayer, 2012; Moreno and Mayer, 2005; Vrugte et al., 2015).

Past research has linked reflection with improved metacognitive function and increased educational outcomes (Bannert, 2006; Fiorella & Mayer, 2012). However, there is wide variation regarding when reflection was prompted (e.g., prior to the game, time based, or activity based), how students were prompted (e.g., menu based, written, spoken, video), and how students responded to the prompts (e.g., spoken, written, or drop-down menu) (Davis, 2003; Hung, Yang, Fang, Hwang, & Chen, 2014; Mayer & Johnson, 2010; Vrugte et al., 2015). For instance, some researchers have used a time-based model to prompt reflection, with Ifenthaler (2012) prompting 15 minutes into the problem scenario and Bannert and Reimann (2012) prompting prior to learning, 15 minutes into the learning environment, and 7 minutes before the end of the session. Both studies reported increased learning outcomes for at least one reflection prompting condition versus a control. More specifically, for Bannert and Reimann's (2012) study, participants in the reflection prompting condition performed significantly more self-regulated learning activities and performed significantly better in a transfer task compared to the no reflection condition; however, there was no difference in motivation as measured by effort and mastery confidence. Conversely, earlier work by Bannert (2006) used an activity-based model for prompting reflection at each navigation step and found the reflection condition achieved significantly higher scores in a transfer task compared to the control condition.

Furthermore, there were several variations in terms of how participants responded to reflection prompts. For instance, several studies required spoken responses (Bannert, 2006; Moreno & Mayer, 2005), others required written responses (Davis, 2003; Ifenthaler, 2012), and still others required that the participant simply answer multiple-choice questions (Kauffman, Ge, Xie, & Chen, 2008; Mayer et al., 2010; Vrugte et al., 2015). There have also been several variations in terms of how reflection was prompted. For instance, several studies presented reflection prompts in the form of multiple-choice questions (Kauffman et al., 2008; Mayer & Johnson, 2010; Vrugte et al., 2015), while others were written (Bannert & Reimann, 2012; Davis, 2003; Ifenthaler, 2012), spoken by the experimenter (Bannert, 2006; Lee et al., 2009), or video based (Hung et al., 2014). A study by Fiorella and Mayer (2012) even prompted reflection using a paper-based worksheet.

To induce reflection, Fiorella and Mayer (2012) used paper-based worksheets listing eight principles related to the material covered in a GBLE about circuits. Specifically, the principles listed eight actions essential to solving the circuit game (e.g., "if you add a battery in serial, the flow rate increases," Fiorella and Mayer, 2012, p. 1077). The game principles sheet was meant to direct the student's attention to the most important aspects of the game and was either already filled in or the student was required to fill it in while playing the game. This study was broken into two experiments; the first focused on whether the paper-based reflection tool (already filled in) improved learning outcomes, and the second focused on whether having students fill in the principles themselves would improve learning outcomes. The results for the first study revealed that the reflection prompt group (principles provided) significantly outperformed the control group on the transfer test and reported significantly lower perceived difficulty and higher levels of enjoyment than the control group (Fiorella & Mayer, 2012). For the second study, there was no significant difference in learning gains between the reflection prompt group (students fill in principles) and the control; however, when the reflection prompt group was divided into a high (participants who got at least six out of eight principles correct) and a low principle group (less than six principles correct), the high principle groups significantly outperformed the control. This means that the reflection worksheet was effective but only for students who could use it effectively (Fiorella & Mayer, 2012). Furthermore, these subgroups (high versus low principle) differed in terms of prior knowledge, with the high principle group having significantly higher prior knowledge than the low principle group. Thus, results revealed that the prefilled worksheet provided significantly more direction than the fill-it-in-yourself worksheet.

This question of how much direction should be provided to support reflection has also been examined by several studies investigating the utility of generic versus direct prompts (Davis, 2003; Ifenthaler, 2012; Lee et al., 2009; Wu & Looi, 2012). Generic and direct reflection prompts were first conceptualized by Davis (2003), guided by the question, is all reflection beneficial to learning? Davis (2003) contrasted two types of reflection prompts, generic and direct, where generic prompts simply asked a student to stop and think, giving very little direction (e.g., "Right now, we're thinking…," Davis, 2003, p. 92), while direct prompts offered stronger hints to guide student reflection (e.g., "To do a good job on this project, we need to …," ibid.). All reflection prompts were given as sentence starters (see the preceding examples), which the student completed. The Davis (2003) study was done in an eighth-grade physical science classroom, where it was hypothesized that generic prompts would be an insufficient reflection scaffold compared to the direct prompts; however, results revealed the opposite findings. More specifically, participants in the generic prompt condition achieved better learning outcomes compared to the direct prompting group. One explanation for this effect was that generic prompts allowed students to take control of their own reflection, grounding their responses in their own thinking at the time, therefore making it more meaningful.

In a more recent study, Ifenthaler (2012) found similar results, with the generic prompting condition exhibiting significantly higher learning gains compared to the direct and control prompting conditions. Furthermore, there were no significant differences between the direct and control prompting conditions. Conversely, Wu and Looi (2012) found no significant differences between a specific and a generic prompting condition; however, these results may be caused by differences in how they defined conditions. For instance, the generic prompt condition in Ifenthaler's (2012) study gave much more information (e.g., "Use the next 15 minutes for reflection. Reflect critically on the course and outcome of your problem-solving process. Amend and improve your concept map if necessary. Feel free to use all materials provided!," Ifenthaler, 2012, p. 43) compared to the direct prompt condition in the Davis (2003) study (e.g., "To do a good job on this project, we need to…," Davis, 2003, p. 92), while Ifenthaler's direct prompt condition gave even more information, making the two studies incomparable even though they used comparable terminology. Wu and Looi (2012) used a learn-by-teaching model and defined generic prompts as leading students to examine metacognitive strategies and beliefs about learning while the specific prompts focused on content. The dramatic differences in prompts between studies illuminate the need for consensus in how researchers define generic and direct/specific prompts. Future research should seek to operationalize generic versus specific/direct prompts to determine the most effective amount of instruction for improved learning gains and what domains to reflect on (e.g., content, affect, or metacognitive skills).

In addition, most studies involving GBL have prompted reflection on metacognitive skills. For instance, Lee et al. (2009) looked at generic versus specific prompts, with generic prompts informing students of the steps and activities they were expected to complete, while the specific prompts provided that as well as metacognitive skills. Note that this is different than in the study by Wu and Looi (2012), further illustrating the importance of operationally defining these constructs. Lee et al. (2009) found that students in a specific prompt condition significantly outperformed those receiving generic prompts but only when performing a difficult task. There was no difference between conditions when the students solved a simple task. Similarly, Wu and Looi (2012) found no significant difference in learning gains between the specific and general prompting conditions; however, they did find significant differences between both experimental conditions and the control condition.

Based on these results, future directions for reflection prompting in GBL include (1) designing empirically valid studies to investigate which reflection-prompting methods lead to improved learning outcomes, and (2) operationally defining the parameters for generic, direct, and specific prompts and further investigating their utility depending on the context. Several studies have investigated whether their reflection-prompting method (e.g., drop-down menu, spoken, written, paper-based worksheet) improved learning compared to a nonprompting condition; however, there is a paucity of research comparing these methods to determine which is more effective, and in areas where they were compared by generic versus direct prompts, there was a lack of general consensus on how these constructs were defined, leading to discrepant findings. Future research should therefore clearly define key constructs and provide explicit and clear descriptions of methodologies, including how reflection was prompted (e.g., by researcher, pop-up window), responded to by the student (e.g., students spoke their response, students typed their response into a prompt window), what students reflected on (e.g., content, metacognitive skills), and when reflection was prompted (e.g., activity based, time based), to ensure replicability and better-informed instructional design based on study findings.

Future Directions

GBLEs remain an exciting and promising area of research in the learning, cognitive, and educational sciences. GBLEs provide a technology platform for further theory development and testing as we continue to find empirically based evidence to support the design and development of these technologies. This can foster and support learning, problem solving, and conceptual understanding across domains, topics, and contexts for learners of varying ages and professions for myriad learning and training outcomes. In this section, we propose a few areas of research where GBLEs are likely to enhance current conceptual, theoretical, methodological, analytical, and educational advances.

Conceptually and theoretically, GBLEs represent a vital technology from which researchers can continue to operationalize abstract constructs such as the ones targeted in this chapter (i.e., self-regulation and reflection) and others (e.g., self-explanation, engagement, motivation, flow). While we reviewed some of the contemporary literature on self-regulation and reflection, there are many more issues related to these constructs that need to be tested empirically. For example, how can we design GBLEs (as research tools) to empirically test assumptions underlying major theories of self-regulation such as Winne and Hadwin's (1998, 2008) information processing theory or Zimmerman and Schunk's (2011) social cognitive theory? How can fundamental assumptions underlying these models and theories be translated into the design of GBLEs so we can test them directly?

While these assumptions have been used in understanding self-regulation with other advanced learning technologies (e.g., intelligent tutoring systems), will they also work for GBLEs? For example, how do we know whether they are monitoring and regulating during GBL when dealing with rapid and dynamically changing game scenarios, adaptive narratives, NPCs, and so on? While our chapter focuses on two metacognitive constructs—self-regulation and self-reflection—how are these two constructs temporally related? For example, does self-regulation occur throughout learning, compared to reflection of a metacognitive process that only occurs in post–problem-solving episodes? Does reflection require prompting because learners do not spontaneously reflect for a variety of reasons? Can self-explanation occur throughout learning? What is its role and function? It seems that one would need to self-prompt, but when, why, how, and would it interrupt one's learning or problem solving? Can a GBLE adapt to a learner's self-explanation, and if so how and based on what, especially when novices and young learners lack the prior knowledge necessary to accurately self-explain? We argue that operational definitions of theoretically derived constructs can be empirically tested in GBLEs.

In addition to these issues, future research can also assess how GBLEs can augment current theoretical conceptions of motivation and emotions, which until now have remained fairly limited because of the overreliance on self-report measures. Despite the widespread implicit assumptions and limited empirical evidence regarding GBLEs' potential to support learning by motivating and affectively engaging learners, additional empirical research is needed to develop a comprehensive model of self-regulation that accounts for cognitive, affective, metacognitive, and motivational processes during learning with GBLEs. We argue for the need to develop such a model in order to measure, track, and understand (1) the nature of the processes and how they individually unfold over time, (2) their characteristics and attributes, such as timescale (e.g., self-efficacy for a specific cognitive strategy changes over hours), duration (from milliseconds to days), dynamics, intensity, valence, sequence, and (3) how they impact each other during learning, problem solving, and conceptual understanding (e.g., negative feedback loops signifying maladaptive behaviors).

Methodologically, these questions concerning motivation and emotions with GBLEs can be addressed by using multimodal multichannel learner data. Emerging research using multimodal multichannel human data (e.g., eye tracking, utterances, gestures, log files, screen recordings, physiological sensors) are invaluable tools to measure, track, and understand self-regulatory processes during GBL, where self-reported data can be aligned with multichannel data to identify behavioral signatures of motivation. For example, what do the behavioral signatures of self-efficacy and task value look like during GBL? Do self-regulatory processes contribute equally, and across time, to each of these complex constructs? Do individual differences contribute to time-related patterns, cycles, or phases? How are behavioral signatures of autonomy, self-efficacy, and engagement directly related to self-regulation and reflection? For example, is self-efficacy evidenced following repeated scaffolding by NPCs during GBL? Which self-regulatory processes, contextual factors, individual differences, and other pertinent data sustain GBL? Are there different types of engagement (Schwartz & Plass, chapter 3 in this volume), such as motivational, cognitive, or behavioral? Do each of these differ both quantitatively and qualitatively over time? What are their implications for the design of GBLEs?

Similarly, we argue that affective data will be measured and subsequently analyzed (1) for distinct emotional signatures within and across data channels; (2) to assess which pattern(s), both within and across channels, is/are most reliable and predictive of cognitive, affective, metacognitive, and motivational SRL processes and performance measures during GBL; (3) for indications of learners' ability to adaptively monitor and regulate their cognitive, affective, metacognitive, and motivational processes with or without scaffolding (e.g., from NPCs or virtual agents); and (4) to assess the temporal sequences among these self-regulatory processes across different subgoals, game levels, and days. Lastly, an emphasis on operational definitions of abstract constructs and their embodiment in GBLEs as research tools will advance the science of learning with GBLEs.

We argue that future research should emphasize system adaptivity based on learners' multimodal multichannel data (Azevedo et al., 2018, 2019). Multichannel data are still rare, and while sensors and data collection have become more accessible to researchers (e.g., affordable eye trackers for classroom research), a prohibitive level of complexity is still involved in integrating and aligning multiple data channels with different sampling rates (i.e., data collected per second). More empirical studies are necessary to identify and generalize associations of specific data channels to measurable products of learning tasks and learning outcomes with GBLEs. In the meantime, researchers must be especially cautious in determining validity, reliability, and applicability of multichannel data within GBLEs.

Self-regulatory processes are sophisticated, co-occurring, and overlapping phenomena. Traditional approaches leverage self-report measures to label and quantify components of these processes. Cognitive measures typically include scoring of answers in learning tasks, quizzes, and embedded tests. Affective self-reports are often used to label emotions at specific moments in time (e.g., every 15 minutes, regardless of what the learner is doing) or activity (e.g., at the end of completing a subgoal). Learners may be asked to make metacognitive judgments of learning or to rate the relevance of content to their subgoal or overall learning goal. However, what if alternatives existed to measure ongoing self-regulatory processes from multichannel data during GBL?

Multichannel data should be leveraged as a tool to identify, validate, and triangulate process-oriented evidence of learning. Do learners show facial expressions that include brow-lowering predominantly during challenging learning tasks? Does skin conductance response show differences between students who are bored and those who are engaged in the learning task? Do these two data channels provide further insight into students' capabilities of self-regulation? For example, does a student notice salient information in a specific location of a GBLE during a difficult task and react to this information by lowering their eyebrows and exhibiting peaks in their physiological arousal? In contrast, does a student who is bored and frustrated simply show brow lowering, with no physiological response? Does eye tracking facilitate identification of affective states, perhaps showing chaotic fixation patterns when a student is anxious or confused? Would the learner's posture combine with eye tracking to disambiguate whether the student is anxious or intently focused on learning? Can multiple data channels provide evidence of real-time changes in motivational constructs, such as goal orientation or self-efficacy? These are the types of questions that future research in the area of GBL needs to address in order to advance the science of learning and design GBLEs that promote, support, and foster effective learning, problem solving, and conceptual understanding.

We conclude with a list of several promising areas of research where GBLEs can advance the science of learning and their educational effectiveness. For example, using GBLEs to deliver training of motivation and emotion regulation strategies (see Gross, 2015; Miele & Scholer, 2018) is paramount in addressing current educational challenges facing our nation. More specifically, strategies for motivation and emotion regulation from research on classroom and clinical research can be embodied in GBLEs that train students to regulate their motivation and emotions in order to take advantage of the affordances of GBLEs. Motivation and emotion regulation training can be combined with cognitive (strategy) and metacognitive (e.g., conditional knowledge) training in GBLEs designed to teach lifelong learning of self-regulatory skills across domains and topics.

Another area is the use of natural language processing that allows learners to communicate directly with the system (e.g., NPCs), which can reveal cognitive (e.g., planning, activating prior knowledge), affective (e.g., impact of negative emotions while collaborating with an NPC), metacognitive (e.g., evaluation of relevant content and emerging understanding), and motivational (e.g., need to increase persistence given upcoming challenge) processes that can facilitate GBL.

In addition, learners can be prompted to reflect on their performance, strategy use, emotional responses, motivational processes between playing levels of a game, and other areas. This type of data can reveal these processes in real time so researchers can understand them and how they unfold over time, and they can be fed back in real time to make the GBLE adaptive and therefore address an individual learner's educational and learning needs.

Lastly, current GBLEs can be integrated with virtual and augmented reality systems to provide a richer educational experience capable of sustaining motivation and emotions, thereby allowing learners to learn, practice, and transfer complex cognitive and metacognitive skills across domains while occasionally self-regulating, self-explaining, and reflecting on their cognitive, affective, metacognitive, and motivational processes during learning.

Conclusions

Overall, the goal of this chapter has been to address self-regulation and reflection during GBL, including what has been done and where we are going. Self-regulation and reflection are both important constructs for learners during GBL, as self-regulation uses monitoring and control strategies *during* learning, while reflection processes require students to look back on their learning *after* they have engaged in self-regulatory processes and make any necessary adaptations to less effective strategy use. Additionally, our aim was to present how different game-based learning environments have fostered self-regulation and reflection, and how this research has led to myriad conceptual, theoretical, methodological, analytical, and educational challenges researchers face when assessing how learners use self-regulatory and reflective processes during GBL. We focused particularly on challenges related to using multimodal multichannel data to assess students' affective and motivational processes, as research on GBL has predominantly relied on self-reported measures to examine these processes and not on how emotions and motivational states temporally unfold over time. In sum, if we can determine ways to measure, in real time, how learners engage in GBL, we can work toward developing adaptive GBLEs that cater to each learner's cognitive, affective, metacognitive, and motivational learning needs.

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10 Adaptivity and Personalization in Game-Based Learning

Jan L. Plass and Shashank Pawar

Introduction

Adaptive games are systems that are able to cater to the individual needs of each user (Plass, 2016). Consider, for example, the game *Mario Kart* (Nintendo EAD, 2013). The game adjusts difficulty by changing the performance of computer-controlled nonplayer characters (NPCs). In *Mario Kart*, if a player is behind in a race, the NPCs start performing worse than usual. On the other hand, if a player is leading in a race, the NPCs perform better than usual. This method makes the game challenging for players with different skill levels. Through the simple mechanism of assessing the player's performance, the game can determine what level of difficulty the player should receive.

An example related to learning is the game *Gwakkamolé* (CREATE, 2017), designed to help learners develop their inhibitory control, a subskill of executive functions (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). In *Gwakkamolé*, players smash avocados that are bold but not avocados that have spiky hats. The resulting repeated need to inhibit the initial desire to smash an avocado will, in time, train the underlying cognitive skill. Research has revealed conditions that make such practice especially effective. These include, for example, that the task should require substantial executive control and that the task's difficulty levels should progressively increase (Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005). Since each learner has different levels of executive functions, the rate of increase will need to differ. Therefore, in this scenario, adaptivity means that the game determines the required difficulty for each user (the adapted variable) based on the accurate diagnosis of learners' current level of inhibitory control (the learner characteristics) (Shute & Zapata-Rivera, 2012). Research has shown that *Gwakkamolé* is more effective when difficulty is adjusted adaptively than when it is increased the same way for all learners (Plass, Pawar, & MacNamara, 2018).

Before we turn to a discussion of adaptivity in game-based learning, there are several terms used by scholars and practitioners that we must define. These are customization, adaptivity, adaptability, and personalization (Plass, 2016).

Customization

Customization allows a player to modify a game based on their preferences. This could include the selection of an avatar, setting specific colors or backgrounds in the system, toggling game sounds, and adjusting other game-specific properties. The goal of these changes is to optimize the acceptance of the game by the player. The results of these changes are, from a learning perspective, relatively minor surface modifications to the game.

Adaptivity

We consider games *adaptive* when they change their features or content based on the diagnosis of individual learner variables, most often the learner's current level of knowledge (Plass, 2016; Shute & Zapata-Rivera, 2012). An important distinction from customization is that changes are based on the assessment of specific learner variables rather than on learner preferences. It is also important that the system actively make these changes in a prescriptive way. The goal of adaptivity in games for learning is to optimize the learning effectiveness of the game; for instance, by maintaining an appropriate level of challenge for each learner. The results of these changes are different learning progressions, methods, or contents for different learners at different points in their learning.

Adaptability

Adaptability implies that a game provides the learner with options and choices that, similar to adaptivity, are based on the diagnoses of specific learner variables. The important distinction from an adaptive game is that an adaptable game leaves the decision of which option to select to the individual. The goal of adaptability in games for learning is twofold: to support the learners' ability to self-regulate their learning and to optimize the learning effectiveness of the game (Boekaerts, 1992).

Personalization

Personalization is a term that has been used to describe learning environments that may combine changes based on learner preferences and those on diagnosed learner variables, both prescribed by the system and chosen by the learner. In other words, personalization is often used as a broader term to describe games that could be customizable, adaptive, or adaptable.

For the remainder of this chapter, we will use the term adaptivity to describe changes in the game that are based on diagnosed learner variables, regardless of whether the game or the user initiates these changes. When this distinction becomes important, we will use the term adaptability to emphasize this fact.

What Is Adaptivity in Game-Based Learning?

The examples and definitions described earlier raise a number of questions. For example, which individual difference variables should be considered for adaptive games? How can the selected variables be measured? Finally, how should the game respond to the diagnosed level of the learner variable? (Shute & Zapata-Rivera, 2012).

What Variable Should the Game Adapt For?

One of the most important questions related to adaptivity is what specific learner attribute to adapt for. Given our definition of an adaptive system, to provide learners with information they need, the first step is to determine what kinds of needs a learning environment should address. Usually the focus of adaptive systems is on cognitive variables—the learner's current knowledge. In fact, the 2012–2013 report *Adaptive Educational Technologies* by the National Academy of Education suggests that adaptive learning technologies "take account of current learner performance and adapt accordingly to support and maximize learning" (Natriello, 2013, p. 7). However, in addition to learner performance, there are many other variables that could be used for adaptive responses; for example, a learner's emotional state, their cultural background, or social variables. Examples are shown in table 10.1.

Even though this table is by no means a complete account of all possible variables to consider as a basis for an adaptive system, it shows that the focus of most current adaptive systems on current levels of knowledge means they only address a very limited number of potential variables to adapt for.

Of course, a particular game can only adapt for a very limited number of variables, possibly only one of them. How should this variable be determined? There are several considerations to take into account that can guide such a decision. The first is whether the variable has been shown to predict the type of learning outcome the game aims to help learners achieve. One of the reasons why a learner's current knowledge is used so frequently as the variable to which the system responds adaptively is the substantial body of research showing that prior knowledge predicts learning outcomes (Bransford & Johnson, 1972; Dochy, Segers, & Buehl, 1999; Shapiro, 2004). However, research has shown similar relations for the other variables listed in the table (Craig, Graesser, Sullins, & Gholson, 2004; Fan & Chen, 2001; Picard, 1997).

A second issue to consider is therefore whether this variable can be assessed within the context of the learning game. Two corresponding questions are whether the variable can be assessed at all and whether such an assessment can be embedded into the game. We discuss these questions in the next subsection. The third question is whether there is enough variability on the variable expected among the learners in the target audience to justify the need for individualized approaches. In other words, would the expected effect size of the gains resulting from adaptivity be sufficient to

Table 10.1

Examples of cognitive, motivational, affective, and sociocultural variables for which games can adapt

Cognitive variables	Current knowledge
	Current skills
	Developmental level
	Language proficiency
	Learning strategies
	Cognitive abilities/skills
	Self-regulation
	Cognitive load
Motivational variables	Individual interest
	Situational interest
	Goal orientation
	Theory of intelligence
	Self-efficacy
	Persistence
Affective variables	Emotional state
	Appraisals
	Emotion regulation
	Attitudes
Sociocultural variables	Social context
	Cultural context
	Identity/self-perception
	Relatedness
	Social agency

warrant such an approach? The fourth and final consideration is whether there is a sufficient theoretical or empirical basis to inform how the system should adapt to the learner differences along the identified variable (Plass, 2016). We discuss this question further.

How Do We Measure the Variable the System Will Adapt For?

There have been many recent advances in measurement of cognitive and noncognitive skills that can provide a foundation for adaptive games (Natriello, 2013; Williamson, Behar, & Mislevy, 2006). In order for a variable to be measured reliably in a game, a number of conditions have to be met. First, a behavior-based measure of this variable needs to exist or needs to be designed and validated. For example, a game that adapts based on the learner's ability to self-regulate their learning would need to be able to measure self-regulation based on the learner's behavior while playing the game (Zap & Code, 2009). Such assessments can be compatible with game design, but they need to be considered in the early stages of the conceptualization of a game (Mislevy, Behrens, Dicerbo, Frezzo, & West, 2012).

The second condition is that the game design must allow for such a measure to be embedded. This involves the design of assessment mechanics (Plass et al., 2013, mechanics that elicit user behaviors that allow the observation of the target variable (Leutner & Plass, 1998). In a game where learners do not have to make choices that require regulation of their learning, such an observation of related behavior would not be possible. In cases where such assessment mechanics can be embedded, the third condition is that it must be possible for measures to be updated in real time. In other words, new user behavior needs to be taken into account to update the learner model. Examples of such real-time measures are Bayes nets that are updated after each learner action (Shute & Zapata-Rivera, 2012). These models of variables should be designed by experts and mapped onto mechanics using a method such as evidence-centered design (ECD) (Mislevy, Steinberg, & Almond, 2003). When using a learner's knowledge as the basis for adaptivity, for example, knowledge space theory has been developed as a basis on which knowledge can be modeled (Doignon & Falmagne, 1985). In addition to using in-game behavior, the measurement of some variables can also involve the use of biometrics, such as facial behaviors to measure emotions (Ekman, Friesen, & Hager, 2002) and affect (D'Mello, Picard, & Graesser, 2007), electroencephalograms (EEGs) to measure engagement (Berka et al., 2007), or electrodermal response (EDR) to measure engagement and emotions (Kapoor, Burleson, & Picard, 2007).

How Should the Game Adapt Based on the Variable?

Once an appropriate variable for adaptivity has been selected, and that variable's assessment in a game has been implemented, the final step in the design of adaptive games for learning is to determine how the game should be adapted based on the determined state of the variable. Figure 10.1 shows the adaptivity loop that involves the observation of learner performance, the diagnostic of the variable of interest, and then the adaptive response of the game. Here, we are concerned with the "Adaptivity" box on the right. How should the game change when, for example, low levels of motivation or high levels of self-regulation skills are detected?

The process of determining how the game should adapt should be based on theoretical insights or empirical evidence that could inform how the system should respond to learner differences along the identified variable (Plass, 2016). Research that investigates how learner variables moderate the effectiveness of an educational intervention is referred to as attribute by treatment interaction (ATI) research (Corno & Snow, 1986; Cronbach & Snow, 1977; Leutner, 1995; Leutner & Rammsayer, 1995; Plass, Chun, Mayer, & Leutner, 1998). However, there have been few contributions to this line of research in recent decades, as it suffered from methodological shortcomings. As a result, many of the variables on learning shown in table 10.1 have been investigated

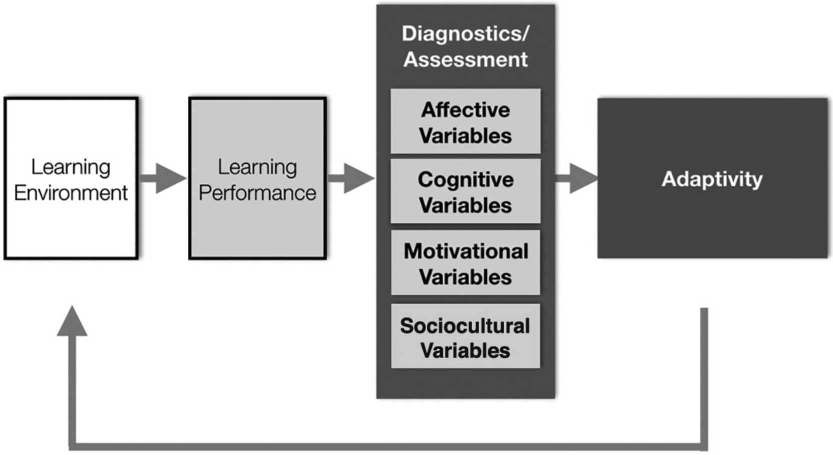

Figure 10.1
Learning environment adaptivity loop.

as general effects, but their interaction with different designs of learning environments has not. This leaves the designers of adaptive systems with the need to first conduct research to determine how the system should respond to specific states or levels of the learner variable of interest. One such example for the design of scaffolding based on a learner's level of self-regulation is described by Azevedo and Hadwin (2005).

The final consideration is which game feature can be used to implement the adaptive response based on the variable of interest. Examples of these features, based on the playful learning design framework by Plass, Homer, and Kinzer (2015) and in chapter 1 of this volume are described in the following subsection.

What Game Features Can Be Used for Adaptivity?

Adaptivity can be implemented in learning games in various ways. Virtually all game components can be designed to adapt based on a player model. In this section, we provide examples of adaptive designs for various game components. This is a nonexhaustive list of examples based on the expanded adaptivity model presented in figure 10.2. This figure shows that these components include scaffolding and cues, feedback and guidance, interaction type, mode of representation,the rehearsal schedule, difficulty progression, and conceptual progression. We discuss examples for how each of these elements has been used for adaptive games for learning.

Scaffolds and cues Scaffolds help players become independently competent with gameplay. They are temporary elements that fade away when players demonstrate a certain level of competence (Reiser & Tabak, 2014). Video games commonly use scaffolds

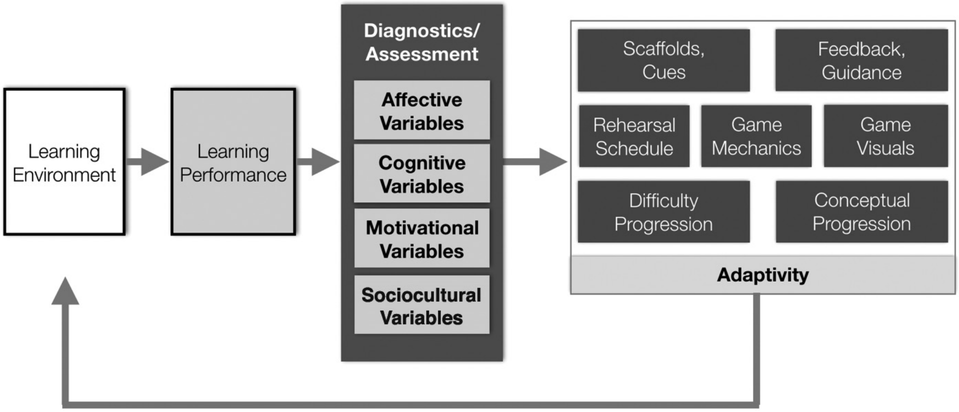

Figure 10.2
Learning game features supporting adaptivity.

to help players learn the game. Nonplayer characters (NPCs), agents that introduce players to game environments and mechanics in the tutorial phase of games, are a common example of game scaffolds. Cues serve a function similar to scaffolds and guide player attention toward important game elements. They can be audio, visual, or haptic in modality and provide subtle guidance to players. Some common applications of cues include distinct visual marking of interactable game elements, such as ladders or ledges to help player navigation, audio clips to signal correct or incorrect actions when interacting with game objects, or controller vibrations on impact with objects in racing games.

Scaffolds and cues can be adapted in games to enhance players' learning outcomes. In *Prime Climb* (Conati, Jaques, & Muir, 2013), a game that teaches number factorization, a pedagogical agent provides scaffolding through gameplay hints. The agent makes inferences based on a student model and displays personalized hints when students are predicted to be missing key domain knowledge. A similar approach has also been implemented in interactive narrative learning games such as *Crystal Island* (Lee, Rowe, Mott, & Lester, 2014) and *Tactical Combat Casualty Care* (Magerko, Stensrud, & Holt, 2006). In these games, an NPC guides players through game scenarios and adaptively provides hints when players are struggling. Adaptive cues are also an effective way to support players during gameplay. With the help of adaptive cues, players' attention can be directed to crucial information at an appropriate time. The language-learning game *We Make Words* implements adaptive visual cues to help players learn new Mandarin words (Demmel, Köhler, Krusche, & Schubert, 2011). It does so by dynamically adjusting the opacity of a silhouette of a word according to players' experience with that word.

Feedback Feedback also helps players with gameplay, but unlike scaffolds and cues, feedback is generated in response to player actions. There is a large body of literature exploring the effects of different types of feedback on learning (Hattie & Timperley, 2007; Shute, 2008). The findings from these studies have inspired many learning games to implement adaptive designs for game feedback. Serge, Priest, Durlach, and Johnson (2013) employed an adaptive design that manipulated the abstraction level of feedback (detailed to general or general to detailed) in a game for learning search procedures. Another way of providing feedback is through NPCs. In *ELEKTRA* (Peirce, Conlan, & Wade, 2008), a game that facilitates learning of optics, a character representing the famous astronomer Galileo provides feedback to players through dialogue. The game *Tactical Combat Casualty Care* (Magerko et al., 2006) implements this by using a military training officer, who talks with cadets to provide feedback. In the game *Graphical Arithmetic Model* (Pareto, Schwartz & Svensson, 2009), players learn by teaching an adaptive agent. The teachable agent develops knowledge based on its interactions with the player. During gameplay, the agent asks questions based on its current knowledge, which in turn is a representation of the player's knowledge level at the time. The questions asked by the agent act as feedback in an indirect way and help players reflect on their learning.

Rehearsal schedule Each player progresses through the game at a different pace. To address differential learning rates, adaptive engines can adjust gameplay time for each player. In addition, games can add, remove, or rearrange game scenarios to cater to individual needs of players. With such an approach, games can provide appropriate practice to each player and ensure mastery of concepts. Rehearsal schedule adaptations are usually implemented through manipulations to game levels or learning modules. In the game *Code Red Triage* (van Oostendorp, van der Spek, & Linssen, 2013), learning modules are structured into tiers. During gameplay, if a player demonstrates competence on tasks of a given tier, the game deletes the remaining learning modules in that tier and introduces modules from the next tier. This allows quick progression to higher tiers and decreases time to completion. A military medic simulation developed by Niehaus and Riedl (2009) builds on this design. It not only removes modules once competence is demonstrated but also adds or replaces modules when more or a different type of practice is required to ensure skills proficiency. A slightly different approach to promote efficient practice is to generate levels in real time. When a player fails at a level in the game *Fuzzy Chronicles* (Clark, Virk, Barnes, & Adams, 2016), instead of repeating the same level, the player is presented with a new level addressing the same learning concept and with the same level of difficulty.

Game mechanics Game mechanics are the building blocks of games (Salen & Zimmerman, 2004). They are independent components that function in an interactive system to generate the gameplay experience. A combination of different mechanics drive the game experience, and adding, removing, or modifying mechanics of a game can lead to big changes in gameplay. Manipulating mechanics therefore changes gameplay in a holistic fashion and allows designers to have more control over adaptivity. For example, the game *Tactical Combat Casualty Care* (Magerko et al., 2006) has an adaptive director that can introduce and move game characters to generate custom scenarios for players. The adaptive director tracks players' demonstration of skills and customizes scenarios accordingly.

A game can also adapt mechanics by introducing new game components. Magerko, Heeter, Fitzgerald, and Medler (2008) used this technique in a game for learning microbiology. They adapted game components based on playing styles. The adaptations were as follows: explorers, who are more intrinsically motivated, received bonus trivia; achievers, who are more performance driven, played with a game timer and a leaderboard; and winners, who are more extrinsically motivated, were provided with a tutorial. These components changed the gameplay substantially, allowing players to play according to their prior inclinations.

Game visuals Visual design of game components influences gameplay. Studies have shown that game visuals independently affect a learner's emotional state (Plass, Heidig, Hayward, Homer, & Um, 2014) and learning outcomes (Ober et al., 2017; Plass et al., 2014). These findings suggest that game visuals play a role in games' learning outcomes and must be considered an important component of the design of learning games. Some learning games have built on this idea and implemented adaptive game visuals. For example, Soflano, Connolly, and Hainey (2015) adapted game visuals in a game for learning Structured Query Language (SQL). In this game, learning content was presented through text or pictures according to the player's preferred presentation format. The game adapted by changing content in the conversational (chat) system of the game. With the help of the adaptive system, players received learning content from the conversational system according to their preference for text or pictures.

Difficulty progression It is crucial to manage task difficulty in learning games. If the game is too difficult, players get frustrated, and if it is too easy, players get bored. To avoid this situation, many games increase difficulty incrementally. Each player, however, learns at a different rate. This poses a major challenge for learning game designers because the preset increase in difficulty can be suboptimal for many players, and unlike in commercial games, in learning games it is important to cater to the needs of each player. To address this challenge, many games adapt task difficulty according to player performance. In the game *All You Can E.T.* (CREATE, 2016), the falling speed of aliens is adjusted to provide players with appropriate time to react before the aliens disappear below the horizon. Similarly, *Cognate Bubbles* (Sampayo-Vargas, Cope, He, & Byrne, 2013), a language acquisition game, adjusts difficulty by manipulating the number of word choices offered to the players. For example, when a player is struggling with a task, the game reduces the number of options, making it easier for the player to make the correct choice.

Conceptual progression Some games implement adaptivity to modify the sequence of learning content. In games with multiple interrelated learning goals, it is possible to rearrange content according to player needs. We use the term conceptual progression for this type of adaptivity because it adapts content based on the conceptual understanding of players. Conceptual progression is exclusive to learning games, as the adaptations are based not on in-game content but on conceptual knowledge of players. *Adaptive Educational Interactive Narrative System* (AEINS) is a learning environment for ethics and citizenship education that provides customized story paths for players (Hodhod, Kudenko, & Cairns, 2009). In this game, stories are customized by arranging teaching moments according to the player model. Teaching moments are domain-level concepts that are part of the whole story, and player interactions with them are utilized for adaptations. By doing so, the game creates a smooth narrative closely coupled with the learning goals.

A macroadaptive approach to conceptual progression is implemented in the math reasoning game *Ecotoons 2* (Carro, Breda, Castillo, & Bajuelos, 2002). The game selects and sequences minigames according to the conceptual knowledge of players. The adaptivity is implemented in two stages: structure generation, and story adaptation through selection of available activities and games. In the first stage, the engine uses player features such as age, primary language, and media preferences to generate a unique game structure for each player. The game structure includes multiple activities themed around an encompassing story. In the second stage, a subset of the chosen activities is made available to the player through an in-game menu. The player can then select one of the available activities. When a player selects an activity, the most appropriate minigame is chosen according to the player's conceptual knowledge at the time. If possible, the minigame is constructed in real time according to the player model; otherwise, a pregenerated version is presented. With this type of adaptivity, the game creates a custom path for the conceptual growth of each player. Having reviewed how adaptivity can be implemented in games, we next discuss research on the effect of adaptivity on desired outcomes.

Research on Adaptivity in Games

Many scientists have studied adaptivity using the value-added research paradigm (Conati & Zhao, 2004; Soflano et al., 2015; van Oostendorp et al., 2013). This allows studying players' learning outcomes with and without an added feature, and making inferences about the feature's effect on learning outcomes (Mayer, 2014). For adaptive learning games, value-added research is conducted by studying adaptivity as a feature.

Most experiments have compared an adaptive version (treatment group) with a nonadaptive version (control group) (Hwang, Sung, Hung, Huang, & Tsai, 2012; Lee et al., 2014). A few studies, however, have used more treatment conditions to investigate multiple adaptive designs (Clark et al., 2016; Serge et al., 2013). For example, Serge et al. (2013) used four treatment groups and a control group to study the effects of adaptive feedback. The detailed feedback group always received direct game-specific feedback; the general feedback group received abstract guidance in the form of general principles; the direct-general adaptive feedback group received feedback that was direct at first but gradually became general; and the general-direct adaptive feedback group received general feedback first, gradually turning into detailed information. This study did not find any significant differences among treatment groups. Clark et al. (2016) conducted a similar study by comparing a nonadaptive control group with two treatment groups. The first treatment group was provided self-explanatory feedback, and the second treatment group received adaptive self-explanatory feedback that changed from detailed to general in the level of abstraction. In this case, researchers found differences in posttest scores between control and treatment conditions, with adaptive treatment getting the highest mean scores.

Along with different research designs, studies have also explored adaptivity for different player traits, including presentation preference, modes of thinking, domain knowledge, and game performance. Soflano, Connolly, and Hainey (2015) conducted a study with an adaptive design based on players' preferences for content presentation. They compared two nonadaptive control groups with an adaptive treatment group. The treatment group received adaptive visuals that changed between text and pictures according to real-time presentation preference predictions of the player. Results showed that the adaptive treatment group outperformed all other groups in postgameplay SQL understanding. Hwang et al. (2012) studied a different type of adaptivity by categorizing players according to their mode of thinking (sequential thinkers and holistic thinkers). They compared a treatment group that played an adaptive version supporting their thinking approach with a control group that received a version opposite to their thinking approach, and found that learning outcomes as well as motivation were higher in the adaptive group.

Many studies have also investigated adaptivity based on domain knowledge (Conati & Zhao, 2004; Lee et al., 2014; van Oostendorp et al., 2013). These studies test the effectiveness of an adaptive engine at changing gameplay by predicting players' domain knowledge. Studies by van Oostendorp, van der Spek, and Linssen (2013) and Lee, Rowe, Mott, and Lester (2014) found that adaptive versions were significantly better than nonadaptive versions when considering learning outcomes. Conati and Zhao (2004) found marginally significant results for the adaptive version of *Prime Climb*, but observed a large effect size ($d = 0.7$). Similar as for domain knowledge, research on adaptivity based on game performance has also yielded promising results (Sampayo-Vargas et al., 2013). Game performance is closely linked to learning outcomes in many learning games and thus can be used as a proxy for the learning progress of players. In a study by Sampayo-Vargas et al. (2013), a treatment group received a version of the game that changed task difficulty based on player performance. This group had higher learning outcomes than the control group.

In addition to studies focusing on adaptivity to enhance learning outcomes in specific subject areas, some investigations sought to determine whether adaptivity could enhance the effectiveness of games that train cognitive skills such as executive functions (Blair & Razza, 2007; Müller & Kerns, 2015). Reviews of such research have shown that adaptivity can indeed enhance executive function training under specific conditions. Two studies by Plass, Pawar, and McNamara (2018) found that adaptive difficulty adjustments in a game to train the *shifting* subskill of EF improved scores for high school students and adults but not for middle school students.

The model for adaptivity shown in figure 10.1 includes four categories to adapt for: cognitive, motivational, affective, and sociocultural. Previous studies, however, have only explored the cognitive and motivational categories (Clark et al., 2016; Lee et al., 2014; Peirceet al., 2008; Serge et al., 2013). Of the two, adaptive interventions have found more success with cognitive factors compared to motivational factors. Adaptivity studies of adaptivity with games such as *Prime Climb* (Conati & Zhao, 2004), *Crystal Island* (Lee et al., 2014), *Fuzzy Chronicles* (Clark et al., 2016), and *Code Red Triage* (van Oostendorp et al., 2013) have succeeded in the cognitive domain, while most studies observing the motivational impacts of adaptive interventions have not found significant results (Peirce et al., 2008; Sampayo-Vargas et al., 2013; van Oostendorp et al., 2013). Some researchers have studied the impact of adaptivity on both cognitive and motivational outcomes (Hwang et al., 2012; Sampayo-Vargas et al., 2013; van Oostendorp et al., 2013). Sampayo-Vargas et al. (2013) observed the effect of an adaptive engine on learning outcomes and player motivation and found significant effects for learning outcomes but not for motivation. Van Oostendorpet al. (2013) looked at engagement as a dependent variable in addition to learning outcomes. The adaptive version of their game helped improve learning outcomes but did not improve player engagement. The lack of motivational effects may result from an inability to increase motivation, which is already high in nonadaptive versions of games. When comparing motivations within the same game, it can be challenging to find significant effects compared to finding effects when comparing a control group and a game group.

Implications

In this section, we discuss the theoretical and practical implications for adaptivity in game-based learning.

Theoretical Implications

Even though no robust meta-analyses of adaptive game-based learning could be found, the studies we reviewed in this chapter provide empirical support for the effectiveness of adaptive games compared to nonadaptive games. This supports the notion that game-based experiences that are able to accommodate the learners' needs can foster learning more effectively than games that use the same approach for all learners. However, the number of variables currently considered for adaptivity is small, resulting in a narrow approach to adaptivity. Most of these variables are cognitive variables; in some cases, motivational variables were considered also. Additional variables should be considered, especially from affective and sociocultural domains. Additional research is needed to investigate the effectiveness of these variables, and we presented a model that may be able to provide useful theoretical and practical guidance for the selection of these variables.

Practical Implications

Our review may also provide guidance for game designers implementing adaptivity in their own learning games. Most importantly, designers should consider all possible types of variables—affective, cognitive, motivational, and sociocultural—for the design of adaptive systems. The selection should include variables that are most likely to vary among learners, while also having an effect on the desired outcomes that have been empirically validated. We described different game features that can be used to implement the different types of adaptivity, focusing, for example, on adaptive scaffolds and cues, feedback, rehearsal schedules, game visuals, game mechanics, the difficulty progression, and the conceptual progression in games. We illustrated considerations required when designing adaptive games for learning and showed that practice needs to be informed by research and theory in order to be effective.

Limitations and Future Research

In this final section, we discuss limitations of current research and provide suggestions for future research.

Limitations

Current research on adaptivity in games for learning has conceptual, empirical, and methodological limitations. On a conceptual level, the way in which adaptivity is defined is very narrow, mostly focusing on a small number of cognitive variables, such as learners' current state of knowledge, and affective variables, such as frustration and boredom. Moreover, many commercial systems that implemented adaptivity do not reveal the way in which the adaptive engine works. This lack of transparency makes it difficult to evaluate the efficacy of these systems. Also hampering adaptive systems is a general lack of research that can guide the design of any adaptive solution. Since attribute-by-treatment research was largely abandoned in the 1990s because of methodological problems, few investigations studied the moderating effect of specific learner variables on learning outcomes. Without this knowledge, the design of theory-based adaptive systems is difficult. Finally, the definition of adaptivity implies that decisions are made for the learner, not by the learner. Conceptually, this is a problem when the ability of learners to self-direct their learning is considered a learning outcome.

Limitations on the methodological and empirical side include the use of variables such as learning styles as the basis of adaptivity. As Pashler, McDaniel, Rohrer, and Bjork (2008) showed, there is no empirical evidence that learning styles have an effect on learning outcomes. As a result, their use as a variable for adaptive systems is not supported by research. Another methodological limitation has been the lack of focus on learner experience. Previous studies have focused on examining various learning outcomes associated with different adaptive designs. However, few studies have discussed the processes through which adaptive systems influence learners' gameplay. For example, studies implementing adaptive difficulty adjustments have not included event-based analysis of adjustments made by the adaptive system and the effect of such adjustments on the learner. Analyzing adaptive systems from a learner's viewpoint can guide future designs and enhance their utility and acceptance.

Future Research

For future research on adaptive games for learning, we propose the following points for consideration, following the questions that guided the first part of this chapter.

What variable should the game adapt for? As our review has shown, the number and breadth of variables that are being used for the design of adaptive games are very limited. Additional research should investigate which other variables should be considered for adaptive games. The list of variables provided in table 10.1 may be useful for selecting learner variables for this research.

How do we measure the variable the system should adapt for? Games collect extensive logs of user behavior that allow predictions of a range of variables. In addition, biometrics allows the collection of physiological data that can be synchronized with the user logs. Finally, contextual data can come from the game and other observations. Together, these data can be triangulated and used to construct new measures for learner variables. Assessment mechanics can be designed to make sure the game produces the kinds of data that will create the kinds of situations that allow observation of the target variable (Plass et al., 2013). These new measures need to be designed and validated.

How should the game adapt based on the variable? A systematic research agenda on how games can be adapted for different learner characteristics should be developed. This includes investigating the moderating or mediating effect of learner variables on the effectiveness of specific interventions, and studying which specific game features should be used for adaptivity. The game features we discussed may provide examples of how adaptivity may be implemented in games for this research.

In this context, it is worth considering whether a new generation of the ATI research paradigm could be developed. An improved approach to these kinds of studies could address the methodological shortcomings that were identified for this research three decades ago based on the new learner variables that were identified since that time and the new measures that were developed to diagnose them.

Finally, future research should expand the overall approach to how the game responds to the learner's needs. Critics already suggest that adaptivity is a new form of behaviorism (Rouvroy, 2015) that prescribes instruction rather than affords learners choices. Researchers should design and study adaptable games; that is, systems that use the diagnosed learner variable to provide the learner with smarter choices and therefore with agency.

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11 Narrative in Game-Based Learning

Michele D. Dickey

Introduction

During the past two decades, digital games have not only emerged as a major form of entertainment but have also become a pervasive form of interactive engagement extending beyond entertainment and into fields such as marketing and education. Within the past decade, the field of learning design has become transformed with the emergence of educational games, edutainment, serious games, and now game-based learning. As popular game design has evolved, so has the burgeoning field of game-based learning. The role of narrative in games was at one time an issue of great debate (Aarseth, 2001; Frasca, 2001; Juul, 2001). Advocates of narrative in games argued that a strong narrative line can create a more immersive and engaging experience for players (Adams, 2001; Bringsjord, 2001), whereas opponents argued that interaction, not storytelling, was central to the gameplay experience (Juul, 1998; Laramée, 2002). Both advocates and opponents concede that much of our concept of narrative has been influenced by media (books and film) that are linear; however, games are integrative environments and as such are not necessarily limited to linear progression. Ironically, the issue of what and how to handle narrative often poses as much of a challenge for learning design as it has for popular game design. The challenge of balancing interactivity with a cohesive narrative is a difficulty that is compounded with the educational goals, learning objectives, and learning needs of game-based learning.

The purpose of this chapter is to examine the role of narrative in game-based learning. The chapter begins with a short explanation of narrative and why it is important. This section is followed by a short summary of how narrative functions in different game genres and of very early research on narrative in educational games and game-based learning. Next is a section describing different examples of narrative in game-based learning: *River City*, *Murder on Grimm Isle*, and *Quest Atlantis*. This section is followed by a literature review of research on game-based learning, focusing on early research, research on speculation and design, and research on the impact of narrative in game-based learning. Following the literature review is a discussion of the different foundational perspectives of game-based learning—cognition, motivation, affective, and socialcultural—and the implications of those perspectives for informing design and integration of narrative for game-based learning. Finally, there is a short discussion about limitations of research, and suggestions for future work.

Importance of Narrative in Game-Based Learning

Narrative is the ubiquitous structure that permeates our lives. It is a connected accounting or retelling of a course of events and experiences as a cohesive and coherent sequence. It is the manner by which humans frame and recount their experiences (Polkinghorne, 1988). It is both a means of reasoning and a means of representation that may be real or fantasy, based not on plausibility of facts but rather on the integrity of structure (Bruner, 1990). Structural linguist Roland Barthes contends that narrative is "present at all times, in all places, in all societies; indeed narrative starts with the very history of mankind; there is not, there has never been anywhere, any people without narrative; all classes, all human groups, have their stories, and very often those stories are enjoyed by men of different and even opposite cultural backgrounds: narrative remains largely unconcerned with good or bad literature. Like life itself, it is there, international, transhistorical, transcultural" (Barthes, 1975, p. 237).

Within the field of game-based learning, narrative is often the story, scenario, and/or framework surrounding and embedded within the learning environment. In one of the earliest inquiries into games and learning, Malone (1981) identified elements in games that fostered fun and fantasy as one of the main elements that supported player motivation. Malone characterizes fantasy as a type of theme, or what we would now consider story or narrative. Malone characterizes fantasy as being either extrinsic or intrinsic to gameplay. For example, in an adventure-style game such as *Myst*, uncovering the story and fantasy is intrinsic to the game, whereas in a game such as *Tetris*, fantasy has little impact on gameplay and is extrinsic to the game. According to Malone, extrinsic fantasy is external to the game, with little to no impact on gameplay, whereas intrinsic fantasy is internal to the gameplay and there exists a reciprocal relationship between gameplay and fantasy. Malone argued that intrinsic fantasy is more interesting and potentially more instructional than extrinsic fantasy, because intrinsic fantasy may be designed to demonstrate how a skill might be used in real-world settings and provide analogies and metaphors to aid understanding (Malone, 1981). Provenzo (1991) and Rieber (1996) identified fantasy as playing a role in motivation in games and addressed how it might be integrated for learning. Along the same lines, Rieber (1996) characterized fantasy as exogenous (external) or endogenous (internal) to the context of educational games and argued that endogenous fantasy is better suited to educational games because it has the potential to motivate learners. To illustrate the difference, Rieber uses the game hangman as an example. Any scenario imposed over the game does not impact gameplay in any way. Endogenous fantasy, on the other hand, is integral to the content of the game; there is no separation between content (fantasy) and gameplay.

Background: Function of Narrative in Game Genres and Early Research

The history of narrative in game-based learning is varied and has been impacted by the evolution of popular games, game genres, and the affordances of technology. It is important to note that early learning design and integration of game-based learning were dependent on the types of game genres and conventions of the time and the technology affordances. Narrative serves different roles in different types of games. In some game genres, such as adventure games, role-playing games (RPGs), and massively multiple online role-playing games (MMORPGs), narrative plays a defining role, whereas in other game genres, such as some sports games, arcade games, and even some action games, narrative tends to be limited to a simple backstory or even merely a themed setting. Among the oldest genres of digital games is the adventure game, with roots that can be traced back to text-based interactive fiction/adventure games such as *The Colossal Cave Adventure* (Hafner & Lyon, 1996; Levy, 1984). Adventure games are interactive stories that place the player in the central role of a character within that story. The purpose of gameplay is to advance the plot through exploration and solving challenges. Adventure games, unlike other game genres, do not include competition, combat, or time management; instead, storytelling is central to adventure games. The conflict within the game is a function of the narrative. Some of the most popular games of this genre include *Myst*, *Riven*, *Syberia*, and *The Longest Journey*.

In role-playing games (RPGs), narrative also plays a central role, but with additional dynamics of character development. The roots of RPGs originated in social table-top games such as *Dungeons and Dragons*. Typically, within RPGs, players begin by creating unique characters, and unlike other game genres, in RPGs players are not assigned a role to play but instead define their own role through the character they create. Narrative plays a significant role in RPGs, though the story line is not as tightly constructed as in adventure games. Story lines typically focus on some overarching goal in which the player's character plays an integral part (e.g., saving the world or at least a kingdom). Story lines typically require players to explore new locales, where they encounter various nonplayer characters (NPCs). The story line may vary, depending on the role the player chooses within the game. Some of the more popular RPGs include the *Final Fantasy* series and the *Elder Scrolls* series.

Similar to RPGs, in massively multiple online role-playing games (MMORPGs), narrative plays a central role, not as a storied adventure but as the environment and framework for gameplay. Typically, within MMORPGs there is no central narrative to uncover but instead an overarching story line of conflict. Narrative is embedded in stories of characters in the environment and quests that players pursue. The choice of quests and the characters encountered result in a narrative that is unique to each player. Among the more popular MMORPGs are *World of Warcraft* and the foundational *EverQuest* and *EverQuest 2*.

In action games, narrative is often limited. The narrative may be a complex mystery or merely serve as a theme or simple framework to situate the gameplay (aliens attacking Earth). In many action games, the environment consists of a series of levels, and the environment of each level is linear in nature, designed for the player to traverse one way. However, newer games allow players to negotiate their own paths through different levels. Similarly, with sports games, simulations, and strategy games, narrative can play a less defining role, serving more as the framework and setting for conflict or goals. What little narrative exists is often in the form of scenarios that may provide a timeline and sketch of conflicts such as the expansion of ancient Rome or the discovery of a new land.

As the role of narrative varies with different genres, so does the role it plays in different types of game-based learning environments. Narrative is varied in how it is used in game-based learning, and because of the complex interweaving of interaction and affordances of technology, it is difficult to separate narrative to access the impact it may have on learning. Compounding the difficulty of separating enmeshed elements of design is the role of artistry in the effectiveness of the construction of the narrative. Writing a compelling story can be difficult and made more difficult through the interweaving of interaction, technology, and learning goals.

Some of the earliest research on game-based learning and narrative focused on adventure-style games in which a narrative story line was central to gameplay. Many of the earliest studies argued that adventure games provide an instructional design model for creating computer-based problem-solving environments (Curtis & Lawson, 2002; Quinn, 1991; Sherwood, 1991). Quinn (1991) used HyperCard to author the adventure-style game-based learning environment *VooDoo Adventure*. In his review of the design, Quinn discusses both aesthetic and cognitive challenges, constructing "problems that contain the desired structure and are also believable" (Quinn, 1991, p. 239).

Examples of Narrative in Game-Based Learning

The emerging field of game-based learning predictably appropriated design strategies from popular entertainment games to integrate into learning design. The use of narrative is central to many types of games and plays a role in the design of game-based learning. The trajectory of narrative storytelling is difficult to separate from both game genres and the evolution of computing technology. As games have evolved, so has the use of narrative in games and game-based learning. Although far from comprehensive, the following review provides some notable examples that illustrate how narrative has been and continues to be integrated into game-based learning.

The earliest educational designers of digital game-based learning designed educational games based on the types of early digital games of the time and in turn integrated the use of narrative into the design of their game-based learning environments based on conventions and affordances of the genres and technologies of that time. Adventure-style games are among the oldest digital game genres, and they typically cast the player in the central role of the protagonist in a story that involves exploration and solving challenges. By exploring, solving problems, and completing challenges, the player uncovers the story. With the advent of computers with graphic capabilities that are more advanced, adventure games developed into graphical environments in which players could view a scene or environment and click on objects to explore or manipulate within that environment. In the remainder of this section, I explore three widely studied adventure games for learning: *River City*, *Murder on Grimm Isle*, and *Quest Atlantis*.

River City

The *River City* project is an often-cited work on the design, development, and integration of game-based learning for science. This adventure-like, game-based learning environment for middle school science students uses a narrative story line to situate the learner in the fictional town of River City, an American city of the nineteenth century. Many of the citizens of River City are currently afflicted with health problems, and students are asked to investigate these problems. Students form research teams to travel back in time to River City and, using their twenty-first-century scientific skills, they research, collect data, and develop experiments to test their hypotheses about the causes of the illnesses afflicting many citizens in River City. *River City* is an immersive 3-D desktop environment in which learners adopt an avatar to represent themselves in the 3-D environment. Learners are free to move through the environment to explore it, gather data, interact with citizens (virtual characters), and examine various records found in the environment. Learners can also select different times of the year to explore the environment and gather data. The interaction with the citizens, artifacts, and environment supports the narrative about the problem with health issues and, in turn, the problem-based goals for finding possible solutions.

Murder on Grimm Isle

Murder on Grimm Isle (Dickey, 2003, 2006, 2007) is a 3-D adventure-style, game-based learning environment designed to foster argumentation-writing skills for language arts students in grades 9–14. The first iteration of this game was authored in 1997 in HyperStudio. The premise begins with a backstory involving the murder of a prominent citizen of the fictional Grimm Isle. Learners are cast in the role of an investigator probing

Figure 11.1
Screenshot of opening animation from *Murder on Grimm Isle*.

the crime scene along with other locales on Grimm Isle to determine the culprit. As learners move throughout the environment, they encounter and collect evidence to help them determine motivation and construct arguments about their beliefs regarding the crime and the culprit. Part of the underlying instructional design relies on Toulmin's model for argumentation (Toulmin, Rieke, & Janik, 1979). The evidence that learners encounter provides support for their arguments.

Murder on Grimm Isle begins with a short video animation of a dark and foreboding mansion framed against a stormy night sky (see figure 11.1). There is the sound of a man crying out in anguish, followed by a thud and the sound of a glass hitting the floor. As the animation progresses, a scenario is revealed in which learners find out they are criminal investigators being sent to Grimm Isle to investigate the murder of the wealthy attorney and environmentalist. They also learn of the long-standing feud between two powerful families on Grimm Isle. Learners are granted search warrants to search the home of the victim (crime scene) and the homes of three main suspects. Learners are provided with additional backstory about some of the complex interplay of dynamics among all four characters. Additionally, learners are informed that a hurricane is headed toward Grimm Isle and are cautioned to remain on task. They are also provided with some initial instructions about how to "travel" within Grimm Isle and how to identify and "bag" evidence.

At the end of the animated backstory, learners are transported to the 3-D environment of Grimm Isle, where they "land" outside the crime scene (see figure 11.2).

Figure 11.2
Screenshot of crime scene from *Murder on Grimm Isle*.

Learners are then free to begin collecting evidence. They may choose to begin at the crime scene or travel to any other location on the isle. As learners encounter objects of evidence, they are able to click on the evidence to reveal more information. Learners are able to bag the evidence to study later. Evidence objects include items such as book covers, a forensic report, a last will and testament, a valentine, and audio voice mail.

The narrative design of *Murder on Grimm Isle* is loosely based on the adventure game genre (e.g., *Myst*); however, it is not an adventure game. There is no single central narrative to uncover; instead, learners uncover evidence that suggests possible scenarios. The narrative design of *Murder on Grimm Isle* draws on the narrative conventions of a "whodunit." Learners are cast in the role of a detective to explore the environment in search of evidence, but there is no single solution or answer. Depending on the evidence learners encounter, they may construct very different narrative story lines. The narrative embedded within the evidence relies on common mystery conventions that help suggest motives for each of the characters. For example, a boot print found at the crime scene may match the boots found in another character's home. Learners' interpretations and subsequent arguments of motive and guilt vary depending on the homes visited and the evidence collected. While this design draws on adventure-style games, it is important to note that *Murder on Grimm Isle* is not a game per se but rather a game-based learning environment. The lack of a single narrative story line is purposeful. It is designed to keep learners focused on the goal of developing their arguments rather than becoming focused on merely revealing a story line to win a game.

Quest Atlantis

Narrative is not the sole domain of adventure-style games, but, as previously stated, it functions differently in an MMORPG. *Quest Atlantis* provides an example of a game-based learning environment rich in extended narrative. *Quest Atlantis* spans several 3-D immersive desktop "worlds" for learners to explore and solve problems in. Like *River City* and *Murder on Grimm Isle*, learners adopt an avatar and move through the narrative-based 3-D environment, interacting with other learners, virtual characters, objects, and data. Each world within *Quest Atlantis* focuses on different types of learning activities, but the overarching narrative of the multiworld environment is an environmentally based inquiry:

> The people of Atlantis face an impending disaster: despite their technological development, their world is slowly being destroyed. In an effort to save their civilization, the Council developed the OTAK—a virtual environment that serves as a technological portal between Atlantis and other worlds. The OTAK features two components, a personalized online portfolio and a virtual 3D space.
>
> The 3D space contains the different worlds created by the Council, and each world features several villages that present a series of challenges called quests, which are designed to help restore the Atlantian knowledge. Through the OTAK, people from other planets can help the Council by engaging in quests and sharing their experience, wisdom, and hope. (Quest Atlantis, 1999)

What is noteworthy about the narrative design of *Quest Atlantis* is that the narrative spans not only different 3-D worlds but also different media, including video, trading cards, and comics.

Although far from comprehensive, these three examples of narrative in game-based learning illustrate ways in which narrative has been and continues to be integrated into game-based learning environments. The following sections will refer to these examples and others as well as provide a review of research on the design and impact of narrative in game-based learning and a discussion of how narrative can support cognitive, motivational, engagement, and sociocultural aspects of game-based learning.

Research on Narrative and Game-Based Learning

Early Research on Narrative in Game-Based Learning

Quinn's work with *Voodoo Adventure* (Quinn, 1991) and *Quest for Independence* (Quinn, 1996) is among the earliest work that addresses the use of narrative for game-based learning. In *Voodoo Adventure*, Quinn used a narrative based on voodoo culture to serve as the problem-solving scenario for his adventure-style, game-based learning environment for anthropology students. Using HyperCard as the authoring system, Quinn created four main areas based on cultural themes and embedded topics and information within those areas for students to explore and learn about culture (Quinn, 1991).

Although Quinn's research on *VooDoo Adventure* reveals little about narrative design for learning, it does address the considerable challenges of adapting the tools to meet the needs of creating an educational adventure game. As technology became more accessible, the creation of game-based learning environments became more accessible and sophisticated and involved uses of narrative that were more complex.

Speculation and design Much of the early work in game-based learning focused on games and conventions of the time; however, within the past decade, digital games have grown in popularity, and with the onset of technologies that are more accessible, the interest in games as a medium for learning has emerged as a major field of study and has yielded an abundance of research. Within this wide body of work, there are many researchers delving into the design of narrative in game-based learning. Initially, the topic of narrative was more speculative in nature, and much work addressed the function of narrative in games and how narrative might be designed and integrated into game-based learning. Sherwood's (1991) work focused on narrative and motivation, addressing how narrative in adventure games provided motivation for cognitive activities such as reading and problem solving. Ju and Wagner (1997) focused on the application of adventure games for training.

Although the focus of their inquiry was on information retention, Ju and Wagner (1997) contend that a rich story line helped create a framework for problem solving. The research of Amory, Naicker, Vincent, and Adams (1999) into student game preferences focused on undergraduate biology students' preferences for game genres. Their inquiry revealed that the students preferred the adventure and strategy games over simulations and identified elements such as graphics, sound, and story line as helping foster skills such as visualization, logic, and memory (Amory, Naicker, Vincent, & Adam, 1999). This work, along with the work of Quinn (1991), Rieber (1996), and Ju and Wagner (1997), helped inform the framework for Amory's (2001) theoretical bases for the development of educational adventure games. Narrative also plays a role in Amory's game-based model, Game Object Model (GOM) versions 1 and 2 (Amory 2001, 2007; Amory et al., 1999). GOM is a framework for linking learning theory (constructivist) to game design. The design, loosely based on object oriented programming, centers on learning objectives as the driving force for developing gamespace, game elements, and narrative to foster learning. Amory maintains that educational games should support learning activities that are "designed as narrative social spaces where learners are transformed through exploration or multiple representations, and reflection" (Amory, 2007, p. 51). Similarly, Neville (2010) compares shared characteristics of narrative and theories of situated cognition and proposes a design rubric for aligning gameplay in game-based environments with performance objectives.

Theoretical work into how narrative and aspects of narrative design foster higher-order thinking in popular games also includes discussions of how narrative elements could be integrated into game-based learning. This includes work by Dickey (2005, 2006, 2007, 2010, 2011a, 2011b, , 2012a, & 2015). Her work elucidates how elements such as backstory, cutscenes, and plot hooks can frame and sustain engagement and provide a narrative environment for game-based learning (Dickey, 2005). In contemporary games, Dickey contends that narrative provides motivation as well as serving as a cognitive framework for problem solving (Dickey 2006, 2007, 2012a), and she postulates that design elements such as Vogler's quest (Vogler, 1998) provide a heuristic for developing narrative in game-based learning (Dickey, 2015). Dickey also maintains that narrative can serve as the overarching framework for learning contexts that are more open, and that narrative models, such as those found in MMORPGs that include different types of small quests, can be designed to correspond to different types of learning objectives to fit within the overarching narrative environment (Dickey, 2007, 2011b, 2015).

As educators and learning designers attempt to grapple with the complexities of adapting game elements for learning, there has been and continues to be much speculation, examination, and projection of how to design game-based learning; however, without a doubt, narrative is a central element in how game-based environments are being conceived. While examination, speculation, and design are fruitful in adding to the dialogue about the role of narrative in game-based learning, research into the impact of narrative is now emerging and provides much insight. As game-based learning continues to evolve as a field of learning design, more research into how narrative functions in game-based learning and the impact of narrative is beginning to emerge.

Impact of Narrative and Design

There is a growing body of work related to the impact of narrative design on learning. It is important to note that the use of the term "narrative" and even "game-based learning" has been characterized in different ways throughout the evolution of games and game-based learning. Some early characterizations for what we would deem as narrative include fantasy, scenario, story, and theme. Similarly, earlier characterizations for game-based learning included adventure games, simulations, virtual worlds, and multiuser virtual environments, along with other terms. This review, although far from comprehensive, focuses on select work that has informed the impact and design of narrative in game-based learning. Although somewhat limited, this body of work includes the design and integration of narrative spanning diverse fields and with different ranges of target learners.

Among the earliest work on the impact of narrative design is Quinn's (1991) exploration of *Voodoo Adventure*, an adventure-style, game-based learning environment for anthropology for undergraduate college students. Although Quinn's investigation focuses primarily on mechanics of design, he identifies the need to find problem-solving environments that can be structured "to contain the specific cognitive characteristics" (Quinn, 1991, p. 237). Quinn claims that the challenge of creating a narrative is that the narrative must provide "a coherent theme within which to embed the problems so that they are intrinsic to the activity. A constraint on the problems is that they must be structured to reflect the desired cognitive property without violating the theme of the story" (Quinn, 1991, p. 239). Although Quinn's (1991) work is focused on the challenges of HyperCard authoring balanced with the instructional design of problem solving, his early work provides insight into some of the complexity involved in creating a narrative that not only supports the learning context but is integral to the cognitive requirements of the learning task.

There is a growing body of work about the impact and design of narrative in game-based learning for various fields of science, including *River City*, *Quest Atlantis*, and *Crystal Island*. Although most of the research resulting from the *River City* project for middle school science does not directly focus on the design and impact of narrative, narrative plays a significant role in the environment. Much of the inquiry into *River City* found that the environment enhanced learning engagement and improved attendance (Dede, Ketelhut, Clarke, and Bowman, 2004). It also supported an inquiry-based environment that motivated learners (Ketelhut, Dede, Clarke, Nelson, & Bowman, 2007). Ketelhut contends that embedding students in science inquiry might "act as a catalyst for change in students' self-efficacy and learning processes" (Ketelhut, 2007, p. 99).

Quest Atlantis has also yielded much insight into narrative design for game-based learning. Although the *Quest Atlantis* project covers many subject areas beyond science, the majority of research associated with this endeavor is related to science education. Unlike investigations of *River City*, some of the vast body of research on *Quest Atlantis* deals directly with both the impact and design of narrative. Barab, Sadler, Heiselt, Hickey, and Zuiker (2007, 2010) present their framework for supporting socioscientific inquiry, which includes the three main components of design: narrative, inscription, and inquiry. The requirements of the socioscientific framework outlined by these authors include a compelling narrative that requires the student to use scientific inquiry to seek solutions but at the same time contextualizes the content and encourages the student to consider political, ethical, and economic considerations in seeking a solution. To meet those ends, they created Taiga Park, a virtual world within *Quest Atlantis*, to support learning about erosion, system dynamics, and environmental awareness.

The narrative of Taiga Park focuses on the park's declining fish numbers and the potential subsequent loss of revenue resulting from that loss if a fishing company leaves because of the decline. Students are placed in the role of an expert who is helping the park manager, Ranger Bartle. Within this complex environmental conflict are three groups—indigenous peoples, a logging company, and a fishing company—embroiled in blame for the decline. As the expert helpers to Ranger Bartle, students interview people, collect and analyze data, and propose solutions. The results of research on Taiga Park reveal that students were engaged with the narrative, and the use of virtual characters elicited affective engagement as well. Because the narrative was not situated in one place but rather was dispersed throughout the environment, in the virtual characters and objects in the environment and in the data collected, student engagement was not that of merely uncovering a story but instead they were co-constructors of the narrative. The qualitative study by Barab, Sadler, et al. (2007) concluded that this type of narrative environment resulted in learners' developing a "rich perceptual, conceptual and ethical understanding of science" because the narrative design contextualized the content by transforming facts and concepts to be memorized into processes and methods for problem-solving and inquiry (Barab, Sadler, et al., 2007, p. 402). The element of narrative within the socioscientific framework engaged students in the process of science and fostered meaningful interactions among learners. As previously mentioned, Taiga Park is only one of the many sections of the *Quest Atlantis* project. Barab, Dodge, et al. (2007) provide insight into narrative within the wider scope of *Quest Atlantis*. According to Barab, Gresalfi et al. (2010), the narrative design of *Quest Atlantis* (dispersed throughout the environment and across various media) fostered motivation for learning but also elicited feelings and emotions as students connected with characters embedded within narratives. Interactions with virtual characters and the narrative environment provide a context for student reflection and dialogue (Barab et al., 2007b).

Crystal Island is another game-based learning environment for science education that has yielded insight into the impact and design of narrative for game-based learning. McQuiggan, Rowe, Lee, and Lester describe *Crystal Island* as a 3-D narrative-centered learning environment that involves a science mystery situated on a recently discovered volcanic island:

> Students are cast in the role of the protagonist, Alyx, who is attempting to discover the identity and source of an unidentified infectious disease plaguing a newly established research station. The story opens by introducing the student to the island and members of the research team for which the protagonist's father serves as lead scientist. Several of the team's members have fallen gravely ill, including Alyx's father. Tensions have run high on the island, and one of the team members suddenly accuses another of having poisoned the other researchers. It is the student's task to discover the outbreak's cause and source, and either acquit or incriminate the accused team member. (McQuiggan, Rowe, Lee, & Lester, 2008, p. 3)

During the course of the mystery, students are guided through the problem-based curriculum as they gather information by interacting with virtual characters and with information gathered in the environment. Based on their research, students prepare a treatment plan for the gravely ill researchers of *Crystal Island* by completing a "fact sheet" that is confirmed by the "camp nurse." Rowe, Shores, Mott, and Lester (2011) conducted an empirical study with 153 eighth-grade middle school students. The findings of that study supported earlier findings that students who were more engaged with the *Crystal Island* narrative environment tended to experience great learning gains and increased problem solving, that students with greater prior content knowledge tended to become more engaged in the learning activity, and that narrative led to greater learning gains and increased problem solving (Rowe, Shores, Mott, & Lester, 2011). Following this study, Lester et al. (2014) conducted a large-scale study to investigate how the integration of a narrative-centered learning environment into the classroom impacted STEM content knowledge, problem-solving skills, and engagement. Similarly, their findings suggest that the use of the narrative-centered *Crystal Island* produced significant learning gains and increased problem solving (Lester et al., 2014).

The initial inquiry by McQuiggan et al. (2008) into the impact of the use of narrative was a media comparison study comparing the use of PowerPoint, a minimal narrative, and a rich narrative. Their results revealed that while students achieved learning gains within the narrative-rich environment of *Crystal Island*, these gains were not as great as those made by learners learning outside the environment who relied on a PowerPoint presentation devoid of all narrative. Similarly, Adams, Mayer, MacNamara, Koenig, and Wainess (2011) used *Crystal Island* along with another narrative-based educational game, *Cache 17*, for a comparison study of student learning retention with narrative game-based environments versus a simple slideshow presentation and found that the simple slideshow resulted in better learning retention.

With that stated, media comparison studies have often been deemed problematic because too often it is not media that are being compared but instead methods of instruction (Clark, 1983, 1994; Warnick & Burbules, 2007). The methods of instruction with an immersive 3-D narrative-based environment differ greatly from learning with a PowerPoint presentation. The outcome may also be determined by what is being measured, and we know from the field of instructional design that different methods elicit different types of learning outcomes. While these media comparison studies are revealing, they may be comparing not apples to apples but rather apples to fish. Where they are most insightful is not in the effectiveness of game-based learning but instead for providing direction in determining which features are most effective with game-based learning.

Subsequent inquiries into *Crystal Island* revealed that engagement in narrative-rich, game-based learning can take the form of engagement in the learning scenario or may be tangential engagement with the aesthetics and interactive elements of the environment. Researchers caution about the risk of including “seductive details” or elements in the game-based environment that might potentially distract, disrupt, or divert student attention from the learning task, resulting in “off-task” behavior (Rowe, McQuiggan, Robinson, and Lester, 2009).

Investigations of the impact of narrative design in the game-based learning environment *Murder on Grimm Isle* focused on how narrative impacted undergraduate students’ motivation, curiosity, reasoning, and transfer (Dickey, 2003, 2010). As previously stated, *Murder on Grimm Isle* is a game-based learning environment designed to foster argumentation-writing skills. The story line involves a murder, and students are cast in the role of the investigator sent to the island to investigate the murder by collecting and analyzing evidence found in the environment. Students use the evidence they find to determine the culprit, and they construct an argument based on their evidence. There is no single narrative to uncover; rather, the narrative differs depending on the evidence collected. Each learner co-constructs the narrative based on their experience in the environment. Findings from Dickey's qualitative study revealed that narrative supported intrinsic motivation, engagement, curiosity, reasoning, and transfer into classroom activities (Dickey, 2010). The narrative design also impacted student interaction and dialogue. Coincidentally, some of the findings about seductive details also support those of Rowe et al. (2009, 2011). Dickey also found that game mechanics elements and aspects of the narrative that had not been included in the learning activity resulted in off-task behavior (Dickey, 2010).

Research on narrative and game-based learning is not limited to K12 and university learning but also extends into areas of training. Bowerset al. (2013) investigated the use of narrative for military training. Their study focused on one aspect of narrative design: character perspective and the resulting impact immersive presimulation narrative would have on stress and performance. What is most insightful about their work is not the results of their study but rather their discussions about first-person versus third-person perspectives on the impact of narrative in emotional engagement and the need for additional narrative study into the effect and impact of third-person and first-person perspectives in narrative design. Finally, Sedano, Leendertz, Vinni, Sutinen, and Ellis (2013) investigated narrative as a game-based learning extension for a museum. They found that narrative fostered and supported affective and cognitive engagement. Like Barab et al. (2007b) and Bowers et al. (2013), Sedano et al. (2013) found that narrative (fantasy) can be designed to impact affective engagement.

Implications for Cognitive, Motivational, Affective, and Sociocultural Theory

In keeping with the central theme of this book, it is helpful to look at the existing body of work about narrative and game-based learning through the lenses of the cognitive, motivational, affective, and sociocultural foundations of game-based learning. These lenses provide insight into how games have been studied and how varying foundations have informed learning design for games. It is important to note that these perspectives are not mutually exclusive categories but instead are different lenses through which to view similar and different aspects of game-based design. There is no comprehensive theory of learning or learning design, nor will there likely be a comprehensive theory for game-based learning. However, using different perspectives on game-based learning to look at different design elements in game-based learning provides a means of identifying patterns to help inform subsequent design.

Plass, Homer, and Kinzer (2015) assert that when games are viewed from a cognitive perspective, the goal of learner engagement is the construction of mental models, and game elements should contribute to the cognitive processing of learning content. Concerns about design are related to the degree to which game elements might overburden mental processes and obscure the goals for learning. If the mind were but a computer, this view of a cognitive perspective would negate the need for this chapter or book, but a cognitive perspective is more than mere computing. According to Plass et al. (2015), the cognitive foundations of game-based learning also encompass situatedness and the context for learning, transfer, scaffolding and feedback, dynamic assessment, information design, interaction design, and gestures and movement. Game-based learning environments are complex systems, and pulling one thread, such as narrative, inevitably reveals the interwoven nature of game elements. However, to help inform design, it is insightful to look at what work about narrative in game-based learning has revealed about the connection between narrative and cognition.

Research from *Quest Atlantis*, *Crystal Island*, and *Murder on Grimm Isle* revealed that the use of narrative in these game-based learning environments impacted student learning. Barab et al. (2007) and Barab, Gresalfi, et al. (2010) found that through participation in the rich narrative of Taiga Park, students developed "a rich perceptual, conceptual and ethical understanding of science" (Barab et al., 2006, p. 76). This understanding was the result of participation with a narrative that involved real-world problems with the accompanying socioeconomic dynamics. Research on *Crystal Island* by Rowe et al. (2011) suggests that students with greater prior knowledge of the content tended to become more involved with the narrative and that more engagement with the narrative resulted in greater learning gains. Subsequent work suggests that the narrative did not negatively impact the cognitive load during the science learning activity and that students learned problem-solving steps through the narrative-based game interactions (Lester et al., 2014). Finally, inquiry with *Murder on Grimm Isle* revealed that students were able to transfer their game-based experience into classroom-based argumentation writing (Dickey, 2010).

According to Plass et al., the motivational foundations of game-based learning "emphasize the ability of games to engage and motivate players by providing experiences that they might enjoy and want to continue" (Plass et al., 2015, p. 268). The underlying assumption has always been that motivation and engagement lead to learning. Malone's (1981) foundational inquiry into what made games fun identified fantasy (which is primed through narrative) as a key motivating element. Yet motivation and engagement do not always equate to learning. Game-based environments may be motivating and engaging, but the motivation and engagement may be in aspects of the game-based environment unrelated to the learning goals. Quinn (1991), Rowe et al. (2009), and Dickey (2010) all reported evidence of students being engaged in but not attentive to the learning activity. Motivation may also be impacted by the elements that support design, such as graphics, music, sounds, and character design. With that stated, narrative helps to foster motivation by providing a mode of inquiry. In *River City*, *Quest Atlantis*, *Crystal Island*, and *Murder on Grimm Isle*, a problem was central to the narrative. In all four cases, learners were cast in the role of a protagonist who must find the solution. In all cases, there were consequences (*River City* involved widespread illness, *Quest Atlantis* involved environmental distress, *Crystal Island* involved widespread illness, and *Murder on Grimm Isle* involved unsolved murder). In all four cases, motivation was also supported with exploration and inquiry. The narrative required learners to explore locations, gather data, and test hypotheses.

The affective perspective of game-based learning centers on the affective domain of the emotions, values, and attitudes of learners. The affective domain is important because emotions drive our attention—which in turn impacts memory and learning (Dickey, 2015). Emotions "influence our ability to process information and accurately understand what we encounter" (Darling-Hammond et al., 2003, p. 90). Ironically, what makes the affective domain difficult is that it is concerned with emotions. Emotions are messy and not easily measured. Similarly, values and beliefs are often culturally constructed, and learners from diverse populations may not share the same belief systems and values, so in many respects it is easier to ignore or sublimate the affective domain and privilege the cognitive domain (Dickey, 2015). As Pierre and Oughton concede, the affective domain is not easily quantified: "Tests of cognitive knowledge can be marked right or wrong, but emotions exist on a continuum" (Pierre and Oughton, 2007, p. 3). The goal of education has traditionally been the acquisition of knowledge, but humans are complex, and the affective domain is important because it impacts the cognitive domain and the psychomotor domain, and vice versa. While it is helpful to view cognition and knowledge as separate domains, humans do not function as beings with separate domains, but rather our emotions are part of how we learn (Dickey, 2015).

Findings from *Quest Atlantis* reveal that narrative can impact emotions of learners, enhancing engagement (Barab, Dodge, et al., 2007; Barab, Sadler, et al. 2007). Similarly, research on *Murder on Grimm Isle* illustrates how engagement is fostered when narrative evokes emotions. Work by Bowers et al. (2013) yielded insight into how narrative design might be used not only to engage learners but also to elicit different emotions. Although relatively little work exists about narrative design in game-based learning and the affective domain, there exists a wide body of work on character design of pedagogical agents and how characters can elicit and impact emotions and values. *Quest Atlantis* provides insight into how creating relatable characters can engage learners who feel emotional proximity to a virtual character. Work on the use of narrative in military game-based environments provides insight into how perspective and voice might support engagement or at times become too emotionally stressful. The limited body of work about engagement has shown that character design in narrative can impact learners' emotions (e.g., empathy, frustration, humor, stress) and their engagement (Barab Sadler et al., 2007; Barab Gresalfi et al., 2010; Dickey, 2010; Bowers et al., 2013).

The sociocultural perspective for game-based learning focuses on learning as a socially constructed process. Sociocultural theory grew out of the work of Lev Vygotsky (1978) and focuses on how social interaction and culture impact learning. Central to this theory is the belief that learners learn from interactions with other people and that learning is shaped by their culture. What is most illuminating about this perspective is Vygotsky's zone of proximal development, which is "the distance between actual development level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). This perspective holds great relevance for the design of games and the integration of narrative into games.

Findings from the integration and impact of narrative from *River City*, *Quest Atlantis*, and *Murder on Grimm Isle* illustrate how narrative design in game-based learning can foster learning through social interactions. In those projects, the narrative provided avenues for dialogue between learners as they verbally (or through text) discussed narrative events, characters, and interactions (Barab, Sadler, et al., 2010; Dickey, 2010; Ketelhut et al., 2007). In those cases, narrative was not situated in one place but rather was embedded in the environment, characters, and objects in the game-based environment. Narrative also created opportunities for scaffolding through the use of characters and by providing resources within the learning environment. *Crystal Island* provides an example of how narrative can help scaffold learning by using a story line that included a lab and text-based resources. Similarly, the narratives in *River City* and *Quest Atlantis* also include scaffolding and prompts. As in *Crystal Island*, the scaffolding and prompts are integrated using characters within the environment. They are also provided through records, documents, and objects integrated into the environment (and within the narrative) to help guide and support learning. The narrative in *Murder on Grimm Isle* includes "evidence" found in one character's home that prompts learners to move to a new location to explore for more evidence.

Implications for Game-Based Learning Design

Just as there is no single central theory about learning, there should not be a single heuristic for the design of game-based learning and narrative. Speculative analysis of narrative in game-based learning has provided insight into how narrative functions in games and how it could be appropriated for game-based learning. Research on the impact of narrative in game-based learning is only beginning to emerge, but research so far has shown that narrative can impact learning from different perspectives. It can impact cognition, motivation, and emotions and provide a framework for social interaction and learning. Yet the research on narrative in game-based learning has some commonalities that provide insight for future design and integration of narrative in game-based learning.

All stories must have conflict, and how conflict is framed shapes a story. Whether the conflict is person to person, person to environment, or even internal, some type of conflict must exist for a story to be viable. In the research on narrative and game-based learning, some genre conventions emerged. Many were mystery-based or problem-based narratives where the central conflict was a type of mystery-based inquiry. Learners were cast in the role (first person typically) of having to explore a problem and find or propose a solution. For example, in *River City*, learners are cast as researchers finding explanations for health problems, and in *Crystal Island*, learners are sent to investigate an illness afflicting researchers. In both projects, students gather data, interview virtual characters, and hypothesize about causes. In *Murder on Grimm Isle*, students are cast as detectives investigating a crime and gather evidence to construct an argument about guilt. In these three narrative-rich, game-based environments, students are cast in the central role and are sent to collect and analyze. The narratives support agency and require interaction to attain the learning objective.

Narrative also supports motivation through multiple means of data representation and through first-person inquiry. Certainly, some of the motivation may result from the novelty of the use of an educational game, and that novelty may lessen as game-based learning becomes more pervasive. Yet, as the novelty declines, narrative in game-based learning becomes more refined and more complex. Although *Quest Atlantis* also relies on an inquiry-based narrative, the narrative design is much broader and allows multiple smaller quest narratives within the environment. Nevertheless, the overarching theme is one of inquiry to help save the people of *Atlantis*. Engagement and motivation are very much related, but there were some findings that illustrate how narrative impacts emotions for learning. *Quest Atlantis* provides insights into creating relatable characters for which learners develop empathy. This in turn may aid in motivation, in an attempt to "help" these virtual characters. Finally, the environmental narrative design, along with communication opportunities, provides insight into developing narratives to support sociocultural aspects of learning by allowing learners to communicate (e.g., *Quest Atlantis*, *River City*, and *Murder on Grimm Isle*) and by providing characters that help prompt and provide guidance (e.g., *Crystal Island*). Ironically, Quinn's insight from his very early inquiries into narrative design and for educational games is still relevant today when he advocates the importance of embedding problems (or challenges) so that they are intrinsic to both the learning activity and the story (Quinn, 1991, p. 239).

Limitations and Future Research

Storytelling is broad, diverse, and encompasses different genres, plots, and character designs. Embedded within the different genres and plots are perspective, voice, and timelines. Research on narrative in game-based learning is just beginning to emerge. While this emerging research provides insight and examples for narrative design, it is important that we acknowledge that storytelling is vast and diverse, and there is much need for more work in both research and design that looks at different game genres as well as narrative genres, conventions, and perspectives.

There is also need for more research on narrative design from both science-based and arts-based perspectives. Games have long been viewed by educators and instructional designers as models for learning design because they induce the types of higher-order thinking skills that are the goal of current education. Yet, regardless of the cognitive complexities evoked, games balance a wide array of aesthetics, which play a large role in how they are realized and experienced. Despite the science-based traditions, the field of learning design is “composed of both art and science” (Harris and Walling, 2013, p. 37). We know from a wide variety of sources that aesthetics influence interactions (McArthur, 1982; Miller, Veletsianos, & Hooper, 2006; Norman, 2004; Tractinsky, Katz, & Ikar, 2000). What is aesthetically pleasing impacts our emotions and, in turn, our behavior. Too often, the topic of aesthetics is relegated to the fringes of learning design. Most of the research that contributes to our knowledge about educational games and game-based learning relies on science-based methodologies to document, describe, and investigate what are also dynamic aesthetic experiences. Science-based modes of inquiry are certainly important for the design of and research into games and game-based learning; however, digital games, like other forms of educational media, such as educational films and television, were primarily established as an entertainment medium. Entertainment media and many forms of fine and performing arts are meant to be felt, sensed, and experienced. Aesthetics are at the core of the arts and artistic media, yet too often science, as the prevailing mode of inquiry, misses the impact and influence of the aesthetics. Science-based methodologies provide a means for gathering and analyzing data, but they do not allow the designer/technologist to “get inside” the experience. Often in research on game-based learning, the role of aesthetics is reduced to some minor notion of graphics or color. Yet, it is the neglected elements of aesthetics that may also have great impact on cognition and learning (Dickey, 2012b, 2015).

Conclusion

Games are complex environments that involve setting, agency, mechanics, and interaction. These elements are realized in the platform, genre, narrative, dynamics, and player interaction. These elements are often tightly interwoven and reliant on each other. Game-based learning compounds the complexity because the intent of a game-based environment is to meet learning needs or outcomes. In a good game, design elements are not discrete components but rather are part of an interwoven, comprehensive whole. Discussion and research on a discrete component tends to blur into other elements. A discussion of narrative in game-based learning is no exception. Good narrative design becomes part of the mechanics, dynamics, player positioning, and character design, and, by extension, narrative design in game-based learning is part of the learning design, scaffolding, and even the learning goals. Although the evidence-based studies on the impact of narrative in game-based learning and its role in fostering learning are very limited and only beginning to emerge, it is an important area of inquiry in the design of game-based learning.

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12 Multimedia Design Principles in Game-Based Learning

Brian Nelson and Younsu Kim

What Are Multimedia Design Principles in Game-Based Learning?

Leading proponents of game-based learning cite many beneficial aspects of well-designed games. Among them is the idea that visually and auditorily rich experiences afforded by digital games support active, situated learning scenarios through which learners can practice real-world skills and apply concepts to solve challenging problems in realistic ways (e.g., Clark, Nelson, Sengupta, & D'Angelo, 2009; Gee, 2014; Mayer, 2014; Shaffer, 2006). In support of realistic scenarios incorporated into many game-based learning environments, researchers and designers frequently create games that feature complex visuals. As Plass, Homer, and Kinzer (2015) describe, the tendency to produce visually rich game-based learning environments can produce designs that conflict with research into the challenges such environments may pose to a learner's ability to process the information they contain. In many game-based learning environments, particularly those that incorporate realistically situated scenarios and narratives, players must process large amounts of sensory information, making real-time decisions about which information is important to remember and which can safely be ignored. Learners do so while also needing to manage sometimes complicated control mechanisms for moving through and interacting with game-based environments and grappling with often complex curricula and associated tasks. The richness and complexity touted as central to the benefits of game-based learning environments can overwhelm learners' ability to process the information they contain (Nelson & Erlandson, 2008). This can lead to tension on the part of designers between the desire to reduce learners' cognitive load and the desire to enhance the sensory realism of the environments (Plass et al., 2015).

Multimedia Design Principles and Cognition

One approach to addressing the complexity challenge in game-based learning is to apply multimedia principles in the design of the game environments. Mayer and Moreno (2003) describe multimedia learning as learning from words and pictures, and multimedia environments as learning spaces and materials to foster learning by supporting the formation of mental representations of incoming information. Mayer, Moreno, and others have described a collection of design principles based on cognitive processing theory for the creation of multimedia learning materials (e.g., Mayer, 2005). These principles offer guidelines for how to arrange and present text, pictures, sounds, and animations to support learning. Generally, application of multimedia design principles aims to lower a learner's extraneous cognitive load (the amount of mental effort used to deal with information that is not centrally related to the learning goals) while supporting germane load (mental effort expended on processing information that is central to the learning goals). There are a large number of these design principles. In this chapter, we discuss a subset of multimedia design principles that have most frequently been examined for their role in game-based learning.

Cognitive Load

Interacting with instructional materials of any type causes learners to experience some level of cognitive load. Sweller, Van Merrienboer, and Paas (1998) describe three types of cognitive loads: intrinsic, extraneous, and germane. Intrinsic load is the cognitive demand inherent in the task itself—the mental effort required to interact with and comprehend some body of material (Nelson, Ketelhut, Kim, Foshee, & Slack, 2013). Intrinsic cognitive load varies with the fundamental difficulty of the subject matter. Inherent difficulty of the material is in turn related to the state of knowledge or experience of learners who encounter the material. For example, the intrinsic cognitive load associated with completing a game-based computer programming task will be high for a novice but lower for students who have done some programming previously.

Extraneous cognitive load is the mental effort imposed by extraneous or irrelevant information presented along with the relevant material. The research into multimedia principles in game-based learning explores whether and to what extent application of specific principles in the design of game-based environments can reduce extraneous cognitive load during learning.

Germane cognitive load (Sweller, Van Merrienboer, & Paas, 1998) is associated with processing information, building mental models to understand information, and developing automation of skills. Germane cognitive load facilitates the achievement of an instructional goal by enhancing the processing of information or aiding in construction of mental models. When the intrinsic load is high (because the material is challenging to the learner) and the extraneous load is reduced (through careful design), the germane load can be increased. As the germane load is increased, the learner has more mental space to focus on the task at hand. In applying multimedia principles to game-based learning environments, researchers and instructional designers hope to reduce learners' extrinsic load in order to foster germane load.

In nongame instructional environments, research has shown that material can be designed and presented using multimedia principles to reduce learners' extraneous cognitive load, which in turn can bolster learning (e.g., Kablan & Erden, 2008; Mayer & Moreno, 2003). Despite the evidence supporting use of multimedia principles in nongame environments, it is not yet clear which of these principles are beneficial in the creation of game-based learning environments. In this chapter, we offer an overview of multimedia design principles in game-based learning. We first provide concrete examples of multimedia principles applied to one of our own educational games. Next, we review the relevant research into the impact of multimedia design principles in game-based learning, focusing on their impact on learning and users' cognitive load. Then we describe some of the implications and limitations of the research for the design of game-based learning.

An Example of Multimedia Design Principles in Game-Based Learning

What does the application of multimedia design principles in game-based learning look like? There are many examples, but here we offer two from our own work. In our Situated Assessment in Virtual Environments for Science (*SAVE Science*) study, we created a game-based environment designed as an assessment platform. In the *SAVE Science* game, middle school science students complete scenario-based performance assessments related to science content they have previously studied in their regular class. Through the *SAVE Science* project, our team worked with middle school science teachers to identify topics they felt were not well assessed via traditional standardized testing methods (generally multiple-choice and vocabulary questions). Our team then selected a subset of these teacher-identified topics for development of game-based assessment modules. These included evolution, physics (force and motion), weather and climate, and gas laws (Ketelhut, Nelson, Schifter, & Kim, 2013; Nelson, Kim, & Slack, 2016).

In our assessment game *Sheep Trouble*, students investigate what is causing a herd of sheep on a country farm to become ill. The underlying assessment goal of *Sheep Trouble* is to measure student understanding and application of concepts of evolution and adaptation to a physical environment over time. Students completing the *Sheep Trouble* module have previously studied the related content in their classroom, using their assigned textbook-based lessons. In *Sheep Trouble*, students meet a farmer who asks for help in finding out why his recently imported flock of sheep is in poor health (figures 12.1–12.4). Students use a question and answer system to communicate with a farmer and his brother (figure 12.4). They can also use a set of interactive investigation tools to interact with flocks of new and local sheep wandering around a farmyard. For example, students can measure the sheep's legs, body length, and ears with virtual rulers; can record and view their measurements of recent sheep weight loss or gain; and

Figure 12.1
Sheep Trouble with no signaling.

can view age and gender information. Once students feel they have gathered enough evidence, they explain their hypothesis to the sheep's owner. Behind the scenes, we record all student interactions and then analyze patterns in the data to understand how well students are able to collect, process, and apply their knowledge and skills to complete the quest.

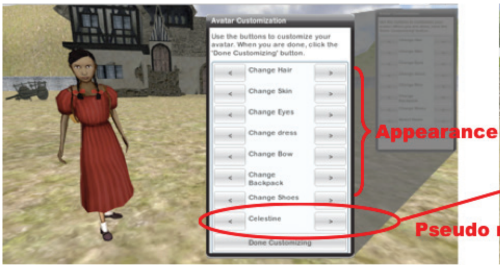
In designing *Sheep Trouble*, we incorporated a number of multimedia design principles, including signaling, personalization, and spatial contiguity. For example, we added visual signals (glowing arrows) to interactive objects, primarily sheep and two human characters (figure 12.2). Following assumptions connected to the signaling principle, the glowing areas were used to direct student attention to relevant content within the game, with the goal being to reduce extraneous cognitive load and increase the frequency of interaction with key assessment elements.

We also created a version of the *Sheep Trouble* module that incorporated the personalization principle (Foshee and Nelson, 2014). In this version, personalization was achieved by creating a customization menu giving students the option of personalizing their avatar's gender and appearance (e.g., choosing the colors of clothing, accessories, eyes, hair, and skin tone) and personalizing their avatar name (from a list of predefined names; figure 12.3). This custom name was then used in all conversations with characters encountered in the game (figure 12.4).

What Do We Know about Multimedia Design Principles in Game-Based Learning?

Multimedia design principles can be distinguished based on their instructional aim: to reduce extraneous processing, manage essential processing, or foster generative processing (Mayer, 2011). Reducing extraneous processing refers to minimizing cognitive

Figure 12.2
Sheep Trouble with signaling.


Avatar Customization

Use the buttons to customize your avatar. When you are done, click the 'Done Customizing' button.


Scientopolis

Scientopolis Resident: Farmer Brown

Oh, Celestine! I hope you are in time to help!

Figure 12.3
Sheep Trouble with avatar personalization.

Figure 12.4
Sheep Trouble with personalized name use.

processing that does not relate to instructional goals (Mayer, 2011). For example, the signaling principle may be applied to reduce extraneous cognitive processing in a game by highlighting materials that are essential to the instruction (Mayer, 2005). To manage essential processing refers to managing cognitive processing required to represent instructional materials. For example, the pretraining principle can be applied to support learners in building connections among concepts encountered in a game-based learning scenario by introducing them to key concepts before they embark on the scenario. Lastly, fostering generative processing involves supporting learners' deep cognitive processing used for understanding the instructional content. For example, the self-explanation principle can be applied to support generative processing of the material in games by asking learners to engage in self-explanations during gameplay (Horwitz & Christie, 1999).

The Games

In our exploration of the literature on the value of multimedia principles in game-based learning, we are drawing from and building on related metareviews by Mayer (2011, 2014) and our group (Nelson, Ketelhut, & Schifter, 2010). As we describe in this section, the findings are somewhat mixed, with some multimedia principles found to be beneficial for learning and/or reducing cognitive load in some games, for some students, some of the time.

It is useful to describe the games themselves before we turn to a review of the studies in which they were used. Table 12.1 summarizes the key aspects of the games. As you read the descriptions, note how varied the games are in their visual design, learning task types, duration, and incorporation of gamelike elements. In Mayer's review (2014), studies of five different games were described, four of which we will discuss in our review: *Circuit Game*, *Profile Game*, *Design-a-Plant*, and *Cache 17*. The *Circuit Game* is a 2-D puzzle game in which students learn how a circuit works by solving circuit problems throughout ten levels. In the game, feedback sounds and points are used as gamelike features. For example, when students solve a given problem correctly, they hear a "ding" sound and are awarded 50 points (Mayer & Johnson, 2010).

The *Profile Game* is a computer simulation in which students try to identify and locate hidden geological features using tools with information on the shape, elevation, and location of the features (Mayer, Mautone, & Prothero, 2002). In the *Profile Game*, students are asked to find hidden geological features by exploring an unknown geographic region represented on-screen. Students can explore by clicking one or two points in a region's image, which provides geological information, such as elevation, in a side window. When students are ready to identify geological features, they can place check marks on features such as a trench, ridge, and others. In the *Profile Game*, additional supports are provided, such as a strategy sheet describing how actual practitioners would perform the tasks and a pictorial support system showing different possible geological features.

Design-a-Plant is a discovery-based learning environment presented in both 2-D and 3-D versions (Lester, Stone, & Stelling, 1998). In *Design-a-Plant*, students travel to different alien planets with different environmental conditions. In the game, students are asked to design a plant that would flourish under specific conditions. A human-like animated pedagogical agent provides supports such as feedback, encouragement, and individualized advice during students' problem solving.

Cache 17 is a discovery-based learning environment situated in a first-person 3-D virtual world (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012; Koenig, 2008). In *Cache 17*, students are tasked with finding their way through an underground bunker to locate missing paintings. As the educational goal, students are expected to learn how electrical circuits and energy work in this context by figuring out how to open doors using electromechanical devices (aided by information on a PDA in the game) and tasks related to recharging batteries and creating electrical circuits. In the game, students are expected to explore the environment, gathering data by using digital tools for navigation, viewing the current task, educational information, and electrical voltage information.

Three additional games for which several studies have been conducted are included in this review: *Crystal Island*, *SimLandia*, and *SAVE Science*. *Crystal Island* is a discovery-based learning environment set in a first-person 3-D virtual world (Spires et al., 2011). In *Crystal Island*, students investigate the nature and the cause of diseases spreading in a research camp. During 60 minutes of gameplay, students explore and investigate the camp by developing questions and hypotheses and then collecting and analyzing data to test their hypotheses. In the game, students can uncover clues and relevant microbiology information by interacting with nonperforming characters (NPCs) and other supplementary data resources (virtual books or posters). The curricula are based on North Carolina's standard course of study for eighth-grade microbiology.

SimLandia is a discovery-based learning environment situated in a third-person 3-D multiuser virtual environment (MUVE) (Erlandson, Nelson, & Savenye, 2010). In *SimLandia*, students collaborate in small teams, controlling human avatars to explore the *SimLandia* virtual world in a 90-minute curriculum. Student teams conduct an inquiry-based investigation to identify the factors causing a severe disease that is spreading throughout a virtual town. Teams gather case data by talking to computer-based residents and by using interactive research tools. Once they think they know the causes of the disease, the student teams formulate a hypothesis and design a study to investigate it.

Earlier, we introduced *SAVE Science*, a 3-D third-person virtual-world game in which students complete performance assessments of science knowledge and inquiry skills (Nelson et al., 2014, 2016). In *SAVE Science*, students control a human-like avatar and investigate problems related to weather and climate, species adaptation and evolution, gas laws, and Newtonian physics (force and motion). In each roughly 30-minute "test," students gather information by asking nonplayer characters preset questions, interacting with in-world objects, and investigating the world itself. Tools are available for students to gather, visualize, and analyze collected data.

The Studies

Studies have been conducted on each of these games, focusing on different aspects of the impact of multimedia principles used in their design. The genre for the studies described here falls under what Mayer (2014) describes as *value-added research*: studies exploring the impact of specific multimedia principles on cognitive processing and learning. Each study compares versions of game environments that incorporate a targeted multimedia principle against a version of the same game that lacks that principle. For our review, we have divided the studies into three broad categories: reducing

Table 12.1

Games and design elements for learning

Game	Type	Environment	Included elements of game design for learning	Intended population
Circuit Game	Puzzle-like	2D window on-screen	Incentive system (points) Musical score (correct and incorrect sounds) Teach new knowledge and skills (learn circuit)	College students
Profile Game	Simulation	2D multi-windows on-screen	Narrative design (find geological identity and locations in unknown area) Teach new knowledge and skills (learn geological features and inquiry skills)	College students
Design-a-Plant	A discovery based learning environment	Virtual worlds either on-screen or head-mounted display	Visual aesthetic design (animated pedagogical character, alien worlds, plants) Narrative design (travel to alien environments and find a plant that will flourish) Teach new knowledge and skills (botanical anatomy and physiology)	Middle school students
Cache 17	A discovery based learning environment	3D Virtual worlds on-screen	Visual aesthetic design (avatar, in-world objects, virtual worlds, PDA) Narrative design (find way out to locate missing paintings) Teach new knowledge and skills (learning how circuit works by opening door using PDA)	Young adults
Crystal Island	A discovery based learning environment	3D Virtual worlds on-screen	Visual aesthetic design (virtual worlds, in-world characters and objects) Narrative design (investigate the nature of and causes for disease in a research camp) Teach new knowledge and skills (microbiology)	Middle school students
SimLandia	A discovery based learning environment	3D Virtual worlds on-screen	Visual aesthetic design (avatar, virtual worlds, in-world objects, research tool) Narrative design (investigate diseases) Teach new knowledge and skills (science inquiry skills)	Middle school students

Table 12.1 (continued)

Game	Type	Environment	Included elements of game design for learning	Intended population
SAVE Science	Situated assessments	3D Virtual worlds on-screens	Visual aesthetic design (avatars, virtual worlds, SciTools, in-world objects) Narrative design (Farmer's recently imported new sheep are ill, find out why) Practice and reinforce existing knowledge and skills (assess scientific content and inquiry skills)	Middle school students

extraneous cognitive load, managing essential processing, and fostering generative processing. Within each category, the impacts of specific multimedia principles on learning and cognitive load are explored.

Reducing Extraneous Cognitive Load

Several multimedia design principles in game-based environments can be applied to reduce extraneous processing. Here we examine studies of three: signaling, redundancy, and immersion.

The signaling principle states that people learn better when the design of multimedia integrates visual or auditory cues that highlight the essential material related to instructional content (Mayer, 2005). By integrating cues into learning materials, extraneous processing can be reduced by directing learners' attention to the key elements and the connection between them. In one *SAVE Science* module, Nelson et al. (2014) investigated the impact of visual signaling in the assessment game. The study, conducted with middle school students ($n = 193$), compared two versions of the game: one that placed visual cues (large glowing arrows) directly above in-world objects that contained data central to the assessment, and an identical version without the visual cues applied. The study measured students' perceived cognitive load and assessment efficiency, which was defined as the number of interactions with assessment-related in-game objects each student completed over the course of the game. The study found that students completing the assessment module containing visual cues reported statistically significantly lower levels of perceived cognitive load and higher assessment efficiency than students in the nonsignaled version (as shown in table 12.2).

As a follow-up study, Nelson et al. (2016) created a more visually complex version of the same assessment game, exploring the hypothesis that visual signaling would have a more powerful benefit when used in a high visual search environment (e.g., one in

Table 12.2

Multimedia principles in games to reduce extraneous cognitive load

Principle	Meaning	Games	Conditions	Test	Effect Size
Signaling	People learn better from a game when cues highlight the organization of the essential material area added	SAVE Science	Visual cues on top of assessment related in-world objects vs. None	Perceived cognitive load	.29
				Assessment efficiency	.34
Redundancy	People do not learn better in games where words are printed and spoken rather than formal style	Design-A-Plant	Narration vs. on-screen text vs. Narration and on-screen text	Transfer	–.22
Immersion	People do not learn better when a game is rendered in realistic 3-D virtual reality rather than in 2-D.	Design-A-Plant	2-D (on-screen) vs. 3-D (Head-Mounted Display)	Retention	–.73
				Transfer	–.30

Adapted and updated from Mayer (2014).

which there are many objects on the screen simultaneously). The study was conducted with a convenience sample of computer science undergraduate students ($n=50$), half of whom completed a nonsignaled version of the game and half of whom saw a version using visual cues identical to those in the earlier study. The study did not find any significant differences in perceived cognitive load or assessment efficiency between the two conditions. In contrasting their findings with the earlier study, Nelson and his colleagues argued that the follow-up study's participants were likely the wrong audience for the assessment content because most answered all the pretest questions correctly (which was not the case with the middle school students in the earlier study).

The redundancy principle in multimedia material states that people learn better when words are only spoken rather than when they are both spoken and printed (Mayer, 2005). The principle has been confirmed to be valid in numerous studies in nongame environments (e.g., Moreno and Mayer, 2002). Theoretically, by removing one source of incoming identical information, a learner can reduce extraneous cognitive processing. However, the redundancy principle may not apply equally across game types and/or for all learners. For example, Moreno and Mayer (2002) investigated the redundancy principle in the *Design-a-Plant* game. In their study, university students were provided with information in the game via animations using narration, on-screen text, or both. The students who encountered either narration or both narration and on-screen text learned better than those who were given on-screen text only. The authors argue that students may have paid more attention to the narration than to the on-screen text, even when both were present simultaneously, because of the exploratory nature of the *Design-a-Plant* game. It may be that students had expectations for how to interact in a game environment, based on prior experiences with similar-looking environments, that predisposed them to focus on narrated information. Both the design of the environment and the students' expertise with similar environments may have shaped participants' level of cognitive load and learning.

The immersion principle in game design states that people do not learn better when a game is rendered in 3-D rather than in 2-D (Mayer, 2014). Mayer argues that realistic details present in 3-D environments may add extraneous cognitive processing, which can limit mental space for essential and generative processing. Moreno and Mayer (2002) investigated the immersion principle with college students ($n=89$) in the *Design-a-Plant* game. The students used one of three different versions of the game: a desktop computer version and two different versions of the game played via head-mounted display (HMD). In the study, students using either version of the HMD-based experience felt a stronger sense of presence in the game but did not show significant differences in retention or transfer tests compared to students using the desktop version of the game. Later, Moreno and Mayer (2004) conducted a similar study with college students ($n=48$) using desktop and HMD versions of *Design-a-Plant*. In this study, the students using the desktop version of the game showed significantly higher gains on content retention tests but no significant differences on the transfer test.

Managing Essential Processing

Here we describe studies of two multimedia design principles applied to manage essential processing (i.e., processing of information central to the learning goals) in game-based learning: pretraining and modality (see table 12.3).

The pretraining principle states that people learn better when they receive pretraining on key concepts before embarking on the main learning experience (Mayer, 2014). By learning key concepts beforehand (i.e., before gameplay), learners can use their limited cognitive resources while playing a game for connecting and applying the concepts. Mayer et al. (2002) investigated the effect of the pretraining principle in the *Profile Game* by providing prior scaffolding (either pictorial scaffolding about geological features or strategic scaffolding about how to solve an example problem). The study found that students who received prior pictorial scaffolding about geological features before playing the main game correctly solved more problems in transfer tests than students who did not receive the pretraining.

The modality principle in game-based learning states that people learn better in games where words are spoken rather than printed (Mayer, 2014). By removing printed

Table 12.3

Multimedia principles in games to manage essential cognitive processing

Principle	Meaning	Games	Conditions	Test	Effect size
Pretraining	People learn better in a game when they receive pretraining in the key concepts	Profile Game	Prior scaffolding vs. none	Accuracy Speed Transfer	N/A N/A .75
Modality	People learn better in games where words are spoken rather than printed	Design-A-Plant	Communication: print vs. narration	Retention Transfer	N/A N/A
		SimLandia	Text chat vs. Voice chat	Content CL	.04
				Communication CL	.15
				General Stress CL	.10

Adopted and updated from Mayer (2014).

text from games, it is thought that learners may free up mental capacity to process animations and other forms of visual information instead of splitting their visual attention between the printed words and other visual elements. Studies by Moreno (Moreno, Mayer, Spires, & Lester, 2001; Moreno & Mayer, 2002) explored the modality principle in the *Design-a-Plant* game with college students ($n=64$ and $n=89$, respectively). In the studies, two versions of the game were compared: one in which learners received explanations through narration and one in which the same information was presented via printed on-screen text. Both studies found that students who received explanations through narration remembered more of the material and earned better transfer test scores than those who viewed printed text.

While Mayer and Moreno's studies showed the benefits of learning narration for receiving information in games, another study saw mixed results when audio was used for communication in a collaborative learning game. Erlandson et al. (2010) investigated the modality principle with college students ($n=78$) in their *SimLandia* game. In the study, two versions of the game were compared: one using a printed text-based system for team communication and one using a voice-based system. Participating teams used the communication tools to collaborate on their investigations in the 3-D game world. In the study, students using voice chat reported significantly lower levels of cognitive load related to communicating with partners and understanding the content in the game compared to the students with text chatting. However, there were no significant differences among groups for overall cognitive load or for gains on a science inquiry and content measure. The authors noted that the convenience sample of university students in the study led to a ceiling effect on the learning measure, with most participants showing high scores on the pretest measure.

Fostering Generative Processing

The studies we describe here have investigated the impacts of six multimedia design principles in game-based environments on fostering learners' generative processing for understanding instructional content: self-explanation, explanatory feedback, prompting, personalization, image, and narrative theme. The multimedia design principles fostering generative processing in games generally centered on guidance-related (self-explanation, explanatory feedback, prompting) or engagement-related (personalization, image, narrative theme) designs (see table 12.4).

The self-explanation principle states that people may learn more deeply in game-based learning when they explain their thoughts, decisions, and/or actions (Mayer, 2014), under the assumption that self-explanation can encourage learners to process material more deeply. Mayer and Johnson (2010) investigated the self-explanation principle in the *Circuit Game* with college students ($n=117$). In the study, students were asked to select the reason(s) for answers they provided in the game from a preset list of reasons based on a logical analysis of game tasks. The students who were asked to select reason(s) for their answers not only outperformed in the transfer test but also learned more quickly than students who were not asked to provide self-explanations.

The explanatory feedback principle indicates that people learn better when they receive feedback on their performance that helps them process the material more deeply (Mayer, 2014). In another *Circuit Game* study, Mayer and Johnson (2010) provided students with explanatory feedback after each in-game question by displaying an arrow over the correct answer and a text box with the explanation of the correct answer. Students who were given explanatory feedback outperformed those who didn't receive the feedback on a transfer test and learned faster than the students who were not asked.

The prompting principle in game-based learning states that people may learn deeply when prompted to reflect on their learning during gameplay (Mayer, 2014). Fiorella and Mayer (2012) investigated the role of prompting in the *Circuit Game* with college students ($n=50$). Participants were given a paper-based prompting aid that directed their attention to relevant features of the game and listed underlying principles related to game actions (constructing electrical circuits). In the study, in an embedded transfer test, students with access to prompting aids outperformed those without them and reported feeling that the content was less difficult. However, self-reported levels of effort during game-based learning were not significantly different between prompting and nonprompting groups.

The prompting principle may apply differently depending on the design and types of prompts. In the second study by Fiorella and Mayer (2012), participants ($n=114$)

Table 12.4

Multimedia principles in games to foster generative cognitive processing

Principles	Meaning (Mayer, 2014)	Games	Conditions	Test	Effect size
Self-explanation	People learn better in a game when they are asked to select an explanation for their moves	Circuit Game	A textbox with eight possible reasons for students chooses vs. none	Transfer test	.91
Explanatory feedback	People learn better in games when they receive explanatory feedback after key moves	Circuit Game	Arrow for correct answers and explanation vs. none	Transfer test	.68
Prompting	People learn deeply in games when they are asked to reflect	Circuit Game	Paper-based aids vs. none	Transfer test	.77
			Requesting to fill out key principles vs. none	Perceived difficulties	1.00
				Transfer	.53 (high principle group)
				Perceive difficulty	N/A
Personalization	People learn better in games when words are in conversational style rather than formal style	Design-A-Plant	1st or 2nd person conversational style vs. 3rd person conversational style	Transfer	1.55
				Retention (Exp 3)	.83
				Transfer	1.58
				Retention (Exp 4)	.57
		SAVE Science	Personalized name and avatar vs. none	Perceived performance	N/A
Image	People do not learn much better in games when an agent's image is on the screen	Design-A-Plant	A pedagogical agent with face, voice, interactive response vs. on-screen text and no pedagogical agent	Retention	N/A
				Transfer	
				Interest	
Narrative theme	People do not learn better in games with strong narrative themes	Crystal Island and Cache 17	Narrative theme games vs. non-game slideshow	Retention	1.37
				Transfer	.57
				Difficulty	.93
				Effort	.49

Adapted and updated from Mayer (2014).

were asked to reflect on their learning by answering printed questions related to principles of circuit design during gameplay. While no overall differences were seen between the group receiving the prompting sheet and the control group, follow-up analysis showed that prompting students who correctly answered most of the questions on principles during game-based learning outperformed control group students, while students who were classified as low performers in the prompting condition showed no differences in learning compared to students in the control group.

The personalization principle as applied to game-based learning states that people learn better from games where words (and images) are presented in a personalized, conversational style. Two studies by Moreno and Mayer (2004) investigated the personalization principle in game-based learning by comparing instructional messages presented to the learner using a personalized style (first- and second-person conversational style using terms such as "you") or a neutral style (third-person text) in the *Design-a-Plant* game. Whether students received the instructional message by narration or by on-screen text, those who received the messages with a personalized, conversational style scored better on transfer and retention tests than students who received messages via a neutral conversational style. Later, Moreno and Mayer (2004) investigated the personalization principle implemented across different levels of immersion (desktop vs. head-mount display) with college students ($n = 48$) using the *Design-a-Plant* game. The study reported that students who received messages in a personalized, conversational style performed better on retention and problem-solving transfer tests than students who received them in a naturalized conversational style, regardless of the immersion level.

A *SAVE Science* study investigated the role of the personalization principle as it relates to student motivation, perceived performance, and engagement (Foshee & Nelson, 2014; Nelson et al., 2013). Data were collected from surveys before and after gameplay and from in-game interactions from 122 middle school students, all of whom used a version of the *Sheep Trouble* assessment game in which they could personalize their avatar's appearance and name. Because *Sheep Trouble* is an assessment game, the impact of personalization on learning could not be logically assessed. However, results showed a positive correlation between levels of motivation for and engagement from personalizing their avatar and high levels of perceived performance in the game-based test.

The image principle states that people do not learn much better in games in which a pedagogical agent's image is on-screen than when it is not (Mayer, 2014). The theoretical rationale for adding an agent's image in educational games is that such images may enhance learning "when learners interpret their relation with the computer as a social one involving reciprocal communication" (Moreno et al., 2001, p.179).

Moreno et al. (2001) investigated the image principle, with varying results, through a series of studies by comparing conditions of the *Design-a-Plant* game: multiple versions of a pedagogical agent condition (i.e., using an animated agent, agent's voice, and interactive responses from the agent) and a nonpedagogical agent condition (i.e., on-screen text and no pedagogical agent). In their first study, 44 college students played the game and then answered retention, transfer, and interest questions. Even though there were no significant mean differences between the two groups on the retention test, the students in the pedagogical agent condition performed better on a transfer test, particularly with more difficult problems, and reported more interest (engagement) in the game. Later, a follow-up study was conducted with 48 seventh-grade students. As in the first study, students showed no mean difference on the retention test, but the students in the pedagogical agent condition performed better on the transfer test, particularly with more difficult problems, and reported greater levels of interest in the game.

Students may see more benefit from the image principle when the game environment allows a higher level of interaction with a pedagogical agent in relating to the learning materials. In a third experiment, Moreno and her colleagues found that college students with access to a more interactive version of the agent performed better on both retention and transfer tests than students with access to one-way transmission of information from the agent.

When narration is integrated with on-screen pedagogical agents in games, the narration aspect (and the modality principle) appears to be more valuable for learning than the image of the agent. In their fourth ($n=64$ college students) and fifth studies ($n=79$ college students), Moreno and her colleagues found that students using a version of the *Design-a-Plant* game with an animated pedagogical agent that delivered information via narration outperformed those using a nonpedagogical agent on retention, transfer, and interest questions. However, presenting images of the pedagogical agent with the narration did not result in any significant differences between groups (in other words, the narration, not the agent's image, seemed to support learning).

The narrative theme principle states that people do not learn better in games with strong narrative themes. The theoretical rationale for adding a rich narrative to a game-based learning environment is that it may motivate learners, leading to greater engagement and better learning. However, the empirical evidence to date seems insufficient to support this rationale. For example, Adams et al. (2012) investigated the role of narrative theme in studies with two games, *Crystal Island* and *Cache 17*. In the first study, participants either played the *Crystal Island* narrative-based discovery game or viewed a slideshow containing the same content as the game, minus the narrative story-line content. The study, conducted with college students ($n=42$), found that students playing *Crystal Island* achieved lower mean scores on a content transfer test, reported more perceived difficulty with the lesson, and indicated more mental effort in completing the lesson compared to students in the slideshow condition.

For their second study, Adams et al. (2012) explored the impact of the narrative theme in the *Cache 17* 3-D exploratory game. In the study, conducted with college students ($n=171$), three conditions were compared: narrative (a version of the game including three minutes of introductory video to present the overarching goal and background story of the game, and NPCs to interact with to get information), nonnarrative (no introductory video), and nongame slideshow (PowerPoint slides used to teach the content covered in the two game conditions). Similar to the results of the first study, use of a narrative theme in the game appeared to be less effective than direct instruction. Regardless of the pretest scores, students in the slideshow condition performed better than those under both narrative and nonnarrative game conditions on the posttest, while there were no significant differences in posttest scores between the groups using the narrative and nonnarrative versions of the game condition. The authors conjectured that students might devote their cognitive processing to materials that are not relevant to learning goals in the game (e.g., the narrative-related details) and suggested that educational games with strong narrative themes may require more guidance centered on instructional goals within the game, more time to allow students to reach learning goals, better connection between the narrative and the educational materials, and finer-grained measures of learning in games.

Implications for the Design of Game-Based Learning

The results from studies to date provide varying levels of support for the value of multimedia principles in designing game-based learning environments. This is hardly surprising. The list of multimedia design principles is extensive, and relatively few have been studied as they relate to game-based learning. However, the literature does help indicate which multimedia design principles show the most promise for game-based learning. As we have described here (and as Mayer found in his 2014 meta-analysis), some principles show particular benefits for learning and/or reduction of perceived levels of cognitive load. For example, having learners conduct self-explanation and/or reflect on their actions during gameplay can benefit transfer. Providing learners with pretraining on key concepts prior to gameplay or supplying them with explanatory feedback on their actions during gameplay also has a strong impact on transfer. Personalizing the text and graphics that students see benefits both transfer and retention of information encountered in games.

The single study into the immersion principle provides strong evidence that immersive 3-D games are not more powerful for learning (despite their higher levels of immersion) than 2-D environments. Similarly, the studies by Adams et al. (2012) show support for the assertion that adding a narrative theme to a game-based learning environment does not bolster learning.

The findings for the use of signaling in games are somewhat less consistent (and less strong). When creating game-based learning environments that include complex visuals and/or complicated interactive functional elements, researchers and developers may wish to implement visual signaling, as it can reduce perceived cognitive load and raises the likelihood that learners will interact with objects in the game in a manner central to the learning tasks. However, the impact of signaling on learning outcomes is not clear. It may also be useful to include elements of personalization (e.g., avatar customization and personalized language).

The implications of the modality principle for game-based learning are somewhat complicated. There is evidence that having players communicate via voice rather than text can reduce perceived cognitive load levels, but there is no evidence that doing so benefits learning. At the same time, studies to date indicate that providing key instructional information through narration can benefit both transfer and retention. In a similar vein, the evidence in support of providing information *only* through narration (rather than via narration and text) is mixed, with some studies finding that learning is not bolstered by redundant sources of information and others finding the opposite.

If one were to gather all the findings described in this review into a prototypical design for a game-based learning environment, it might look something like a 2-D, nonnarrative-based game in which players guide customized avatars through a series of tasks. Before embarking on the main game tasks, the players would receive pretraining on key concepts. In-game objects related to the tasks would feature visual cues to direct players' attention to them. Players would make choices as they complete the tasks, receive regular explanatory feedback, be asked to explain their actions as they go, and occasionally stop to reflect on their actions. Instructional information and feedback would be provided to the player through narration alone, with minimal printed text being provided.

This prototypical design is not bad, but it seems quite distinct from many existing successful commercial and educational games. Indeed, we argue that its design may have more in common with traditional instructional systems than with game-based learning environments. This raises some interesting questions about how to approach research on the role of multimedia principles in game-based learning and leads to our discussion on the limitations of current research.

Limitations of Current Research and Implications for Future Research

There are limitations on current research into multimedia principles for game-based learning that inhibit our ability to make generalizable claims about their value for managing cognitive load and bolstering learning. The first is that the design, learning goals, and approach to learning in educational games vary tremendously across game environments. The review we have provided here is not exhaustive, yet still includes 2-D and 3-D games, exploratory games, games with and without directed instruction, featuring strong narrative story lines and no narrative themes, science inquiry games, simulations, puzzles, and assessment games. This wide variety makes it a challenge to apply findings seen in any single study to all game-based learning environments. For example, visual signaling found beneficial in a 3-D exploratory game may not be necessary for a visually simple 2-D game. The benefits of providing information via narration versus text may be powerful in a game with little instructional content but less useful in a scenario-based game centered on gathering, sorting, and analyzing text-based data (Mayer, 2011).

A second limitation relates to the design of the games themselves. As educational game visionary Jim Gee has stated, "I never said bad games are good for learning" (personal correspondence, 2011). In both the commercial and educational fields, it is challenging to design good games. Our team has struggled with this challenge. Despite the best efforts of our team over the years, the educational games we have created are not of commercial quality, either in graphics or in the design of the games as games. Game-based learning environments created by education researchers can look game-like but may lack fundamental design elements that make them games (i.e., challenge, competition, collaboration, internal consequences, meaningful player choices). Relatively low budgets, small design and development teams composed of students, and short development time frames all contribute to the issue.

Consequently, many game-based learning environments may not provide strong foundational learner experiences from which to build studies of value-added multimedia principles. If the control version of a given game lacks elements of game design said to be beneficial for learning, lack of significant findings in support of learning around a given multimedia principle may have more to do with the game than with the principle. Conversely, a study finding positive evidence for learning when a given multimedia principle is applied to an environment that more closely resembles a traditional instructional system than it does a game provides evidence only for the specific environment rather than for game-based learning in general.

Another limitation of current research into the value for learning of multimedia principles in games is a mismatch between the time frame of the study implementations and the time that may be required to learn well within games. The bulk of the studies cited in this chapter had participants play a game for a relatively short period. For example, each of the *SAVE Science* studies saw students completing a given assessment game in roughly 20 minutes. Games researchers generally tout the learning benefits of games that come from engaging with a given game over time (e.g., Gee, 2014; Shaffer, 2006). As with more traditional instructional materials, it may be difficult to see benefits to learning from interacting with a game-based learning environment only one time and for a short duration. For example, Adams et al. (2012) note that the use of narrative themes in games may be more beneficial when applied to games in which players spend longer periods of time.

Research into the role of multimedia principles in game-based learning is still in its relatively early stages. As this review shows, the findings to date are mixed but quite valuable in their insights into designing game environments that support learning. There is a rich set of studies yet to be conducted, principles to explore, and game-based learning environments to systematically investigate.

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13 Collaboration and Competition in Game-Based Learning

Fengfeng Ke

Introduction

Prior research on collaboration and competition in a learning situation has usually conceptualized the two social processes or situations as alternative types of goal structures by which learners interact and behave in learning activities (Deutsch, 2006; Johnson & Johnson, 1974). In collaboration or cooperation, there is a positive interdependence among individual learners' goal attainments—an individual can attain his goal if and only if the others with whom he is linked can obtain his goal; in a competitive situation, the goal interdependence is negative—individuals attain goals only if their peers do not, and they are expected to outperform their peers (Deutsch, 1962; Johnson, Johnson, & Stanne, 1986). In comparison, an individualistic situation occurs when the goal attainments of individuals have no bearing on and are independent of each other.

The collaborative and competitive goal structures in learning are frequently arranged or motivated via extrinsic reward structures—the individual learner's rewards for performing a task are positively proportional to the quality of group work or negatively proportional to the quality of work of others doing the same task, respectively (Kelley & Thibaut, 1969). Prior research examining the cognitive and affective outcomes of collaborative and competitive structures in learning has generally reported that both structures as well as an individualistic one hold both positive and negative components and should be used in alignment with other facets of the instructional situation, such as instructional objectives, learner characteristics, group configuration, and the nature of a learning activity (Peng & Hsieh, 2012). It was argued that collaborative learning is the preferred instructional procedure when a higher level of learning outcome, such as complex problem solving (versus simple drill activities), and competence in interpersonal learning interactions are involved (Johnson & Johnson, 2009; Johnson, Johnson, & Smith, 2007). Furthermore, intergroup competition has been used in combination with intragroup collaboration to maximize opportunities for student learning (Johnson & Johnson, 1999).

Recent examination of collaboration and competition in a computer-supported learning situation has seen a shift from contiguous learning partnership to technology-mediated interaction space that integrates different goal structures and may not involve a human partner. Specifically, competition (or challenge) in a digital game-based learning system is a salient and integral gameplay element that could emotionally and cognitively engage players. Competition comes in multiple forms—one can compete against the system, against oneself, or against others (Alessi & Trollip, 2000; ter Vrugte et al., 2015). Endeavors at overcoming obstacles in a game task are considered competition that is a productive constraint and could have a significant impact on learning and motivation (Dewey, 1958; Shaffer, 2004). Similarly, collaboration or the social component, either with nonplayer characters or with other players, is identified as a core design mechanism of digital gaming (Peng & Hsieh, 2012; Yee, 2006). Collaboration in game-based learning reflects the fundamentally social nature of the learning process by focusing on active interactions in support of learning that may or may not involve the context of working toward a shared goal, thus affording broader opportunity than conventional cooperative learning which typically implies a shared purpose (Shaffer, 2004).

In spite of the fact that both collaboration and competition are established and integral features of digital gaming, research examining the purposeful design of collaboration and competition and their cognitive or affective bearings on game-based learning is still limited and sporadic. Evidence regarding the effects of collaboration and competition is mixed, including an extrinsic reward structure or an intrinsic component defining the nature of game-based learning. A coherent or systematic framework guiding the interpretation and practice of collaborative and competitive gameplay for learning and learner success is also lacking. Hence, the aims of this chapter are to describe the nature and examples of collaboration and competition in game-based learning, provide a descriptive review and synthesis of recent studies designing and evaluating collaborative and competitive gameplay for learning, and explore the theoretical and design implications of the current empirical findings.

Manifestation of Collaboration and Competition in Game-Based Learning

The occurrence of collaboration and competition in game-based learning can be scripted or purposefully designed as a game-external learning activity, or part of game mechanics—rules that dictate how the game system behaves—that frame alternate modes of gameplay. Collaboration and competition may also emerge as a voluntary enactment by learners during gameplay and be manifested as the inherent social nature or as a by-product of any gaming or game-based learning processes.

Designing the processes of collaboration and competition as a game-based pedagogy—the contextual reward or goal structure that confines game-external learning activities—is a common practice in educational gaming. For example, in the works of Ke (2008) and ter Vrugte et al. (2015), collaboration and competition were employed as alternate external grouping structures: players would play collaboratively (e.g., playing on the same device together in dyads), competitively (e.g., playing against others by comparing individual gaming performance), in an integrative way (e.g., via intergroup competition, where the team performance was the aggregation of individual members' gaming performances), or individually. It should be noted that in those cases the external gaming contexts or social conditions are not necessarily in alignment with the internal game mechanics, and hence a single-player game can be integrated into a collaborative or competitive learning procedure. The purpose is to explore the optimized implementation context of educational games or, particularly, to examine the interaction between the external social interaction contexts and the internal gameplay on players' cognitive and affective engagement and their game-based learning outcomes.

Another salient subject of educational gaming is to explore how game mechanics based on principles of collaboration or competition, such as modes of gameplay and game reward/scoring mechanism, will impact the performance and engagement of players in game-based learning. Common design patterns of serious games (or games with a purpose) rely on the principle of collaboration, while entertainment-oriented games are frequently designed around the principle of competition, where players compete to outperform each other (Siu, Zook, & Riedl, 2014). Recent design and research of serious games has tended to integrate collaborative and competitive mechanics into multiplayer modes. For example, a multiplayer online game called *Foldit* engages players in solving complex protein structure prediction problems and supports both competition and collaboration between players (Cooper et al., 2010). The primary gaming action is individual play—interacting with visualized protein structures using direct manipulation tools. For collaboration, players can share solutions within a group and help each other with strategies and tips through the game's chat function, where a successful solution results from multiple online players collaborating to solve the same scientific problem. For competition, both individual and team players' performances are ranked, and the top performers tackling the same puzzle are displayed on a leaderboard. Cooper et al. (2010) reported that the competition and collaboration aspects of gameplay alter the aggregate search progress of *Foldit* and heighten player motivation. In other cases, the collaborative, competitive, and individualistic versions of gameplay were created solely via the game's scoring mechanism. For example, in the study by Plass et al. (2013), an arithmetic drill and practice game called *FactorReactor* enables individual, competitive, and collaborative modes of play by rewarding or scoring the same primary gameplay action differently—playing the game to get the best score one can, to compete against each other for the best score, or to work together to get the best score. Correspondingly, the major gameplay screen will display the performance status and gameplay control of the individual player, the paired competitive players, or the cooperative player team.

Adopting the perspectives of game flow and computer-supported collaborative learning (Sweetser & Wyeth, 2005), certain games and studies have depicted collaboration and competition as the inherent and underlying facets of the motivational appeal of gaming. For example, simulation games that aim to engage learners in vocational learning would employ collaborative design problem solving or decision making as the primary gameplay actions, and thus the involvement in collaboration—in-game peer communication and conflict resolution—became not only the means but also the ends of gaming (Hämäläinen, 2011; Wendel et al., 2010). In other games, competition acts as a key social interaction element to reinforce game flow experience. For example, a key gameplay rule of massive multiplayer online games is individual or intergroup competition (Paraskeva, Mysirlaki, & Papagianni, 2010). Hwang, Wu, and Chen (2012) described a competitive online board game for science learning in which each location of the virtual game board corresponded to a minigame (i.e., information-search quests presented as a jigsaw puzzle or as a matching or shooting game) and players determined their moves by throwing dice. A player's status and the top players were displayed and ever present on the game stage. The authors reported that game-based competition promoted the flow experience, learning motivation, and web-based problem solving.

Research on Collaboration and Competition in Game-Based Learning

A review of prior research on collaboration and competition in digital game-based learning was conducted by searching the electronic databases Academic Search Complete, Education Full Text, and ERIC for peer-reviewed articles from the past 10 years, using the search terms *game-based learning*, *collaboration (collaborative)* or *cooperation (cooperative)*, and *competition (competitive)*. After an initial electronic search and further screening via both abstract and full-text reading, 15 studies met the following criteria and were included in this review: (1) purposefully designing and investigating the process of collaboration and/or competition for game-based learning, (2) focusing on gaming for academic learning, and (3) reporting empirical evidence of game-based learning.

The review indicated that the studies varied in their manifestation of and goal for collaboration and competition in a game-based learning environment. The evidence on the impacts of the two alternative gameplay or learning structures on cognitive and affective learning outcomes is still inconclusive. A descriptive synthesis of studies reviewed that is organized based on the design and nature of collaboration and competition in gaming follows.

Collaborative and Competitive Goal Structures for Game-External Learning Activities

Among the 15 studies reviewed, eight have implemented collaboration and/or competition as game-external learning activities. Among these studies, five (Chen & Law, 2016; Chen, Wang, and Lin, 2015; Sung & Hwang, 2013; Van der Meij et al., 2011,

2013) mainly used a collaborative postgaming learning process as an external learning support, while the three others (Ke, 2008; Ke & Grabowski, 2007; ter Vrugte et al., 2015) used them as an external goal or grouping structure.

Collaboration and/or competition as external learning support Collaboration has been designed as an external support feature—peer discussions during or after gaming that are often aimed at the explication of implicit knowledge derived from gameplay (Wouters & van Oostendorp, 2013). The meta-analytic review of the instructional support in game-based learning by Wouters and van Oostendorp (2013) reported that the instructional support classified as collaboration type improved learning ($d = .14$, $p < .05$), yet the effect is too small (especially when compared with that of personalization, $Z_{\text{personalization–collaboration}} = 3.17$, $p < .001$).

Chen and Law (2016) investigated collaboration as the structure of peer-facilitated soft or dynamic scaffolds, with a hypothesis that collaboration would enable players to exchange explanations and negotiate meaning to co-construct cognitive structures and cultivate positive attitudes toward the task. The study compared the process of collaboration (where school students played the game together and were voluntarily involved in discussion during gaming), collaboration plus hard scaffolding (i.e., postgaming, open-ended prompts to promote explicit connections between the game world and disciplinary knowledge), individual gaming with hard scaffolding, and individualistic gaming. The game was a three-level drill-and-practice game targeting conceptual understanding of force and action and designed for individualistic gameplay. The study indicated that both hard scaffolding and collaboration promoted positive performance on knowledge tests. Interestingly, the presence of hard scaffolding strengthened the positive relationship between collaboration and student performance. Moreover, only with the presence of hard scaffolding would collaboration show a positive impact on self-reported task motivation. In an earlier study, Chen et al. (2015) examined the use of the same game in the condition of individualistic gaming and that of collaborative gaming (i.e., playing together plus postgaming collaborative group debriefing). The study did not find that gaming conditions had a significant effect on game-based learning performance, though collaborative gaming promoted higher self-efficacy and expectancy for success. The authors reported certain personality traits of, and the conflict between, individuals in a group might have negatively impacted group dynamics to diminish collaborative learning. The studies by Chen and colleagues (Chen et al., 2015; Chen & Law, 2016), in general, suggested that the effectiveness of using collaboration as an external support for game-based learning would be mediated by group dynamics and other learning support features.

Similarly, Sung and Hwang (2013) designed collaborative information grid making as the add-on learning-support activity to promote information organization in a role-playing game that aimed to teach conceptual knowledge of natural plants. They examined the combination of collaborative gaming with collaborative grid making compared to collaborative gaming only (where students played the game in small groups without making grids) and individualistic gaming. They reported that collaborative gaming along with collaborative grid making, compared to the two other conditions, promoted learning achievement, attitudes toward science, learning motivation, and self-efficacy significantly better. One interpretation was that collaborative external learning support focuses learners' collaboration on information organization rather than on gameplay itself.

Van der Meij et al. (2011, 2013) also examined the potential impact of collaborative debriefing as a game-external learning support process in a commercial strategy game on the law of supply and demand in business. Different from Sung and Hwang (2013) and in agreement with Chen et al. (2015), both studies of Van der Meij et al. (2011, 2013) did not indicate an impact of collaborative postgame debriefing on game-based learning outcomes, and individualistic debriefing actually improved game-based learning more than collaborative debriefing. The studies reported that after-play game talk focused more on superficial rather than fundamental game features or strategies and argued that scaffolding for collaborative debriefing is warranted to support reflection on fundamental knowledge to be derived from gaming.

In summary, using collaboration as a game-external support for information articulation and organization was found to potentially promote game-based knowledge development and affective learning outcomes. Yet, its impact was moderated by the presence of a scaffold or learning-oriented protocol for the collaborative knowledge construction process and group dynamics.

Collaboration and/or competition as a gaming context With the intent of exploring game-based pedagogy or examining the potential mediation of external goal and reward structures on the gameplay flow, certain scholars examined the mediation effects of collaborative, competitive, and individualistic gaming contexts on gaming performance and game-based learning. In two earlier studies (Ke, 2008; Ke & Grabowski, 2007), a structured intragroup cooperative (with intergroup competition) gaming context was compared with solely competitive and individualistic gaming contexts for a multilevel math game targeting mathematical calculation and problem solving. Their findings demonstrated that the cooperative gaming context better promoted positive attitudes toward mathematics than the two other gaming contexts, especially for socioeconomically disadvantaged students, whereas the individualistic gaming context better facilitated math knowledge test performance compared to the others. In agreement with Van der Meij et al. (2011, 2013), Ke (2008) found an absence of cognitive elaboration among group members during cooperative gaming. A more recent study by ter Vrugte et al. (2015) used a similar research design while adding a fully collaborative gaming condition as an alternative gaming context. The result of their study was generally consistent with that of prior research in that no main effects of collaborative and competitive external contexts on game-based learning were found. Yet, below-average students experienced a positive effect of collaboration on learning, whereas above-average students experienced the reverse. It should be noted that all three studies used mathematical games that were originally designed for individual gameplay and focused on the practice of mathematical procedural knowledge and problem solving rather than the development of conceptual understanding.

Collaborative and Competitive Game Mechanics for Learning

Seven studies reviewed integrated collaboration and/or competition as an inherent component of gameplay (or mode of gameplay) via the internal game scoring rules for the primary gaming action. Five of them (Pareto, Haake, Lindström, Sjödén, & Gulz, 2012; Peng & Hsieh, 2012; Plass et al., 2013; Siu et al., 2014; Tsai, Tsai, & Lin, 2015) examined learning games designed with multiple modes of gameplay, while two (Hummel et al., 2011; Hung, Young, & Lin, 2015) focused on collaborative gameplay mechanics.

Multiple modes of gameplay via internal game scoring rules A recent review of game-based learning (Abdul Jabbar & Felicia, 2015) reported that the most common play mode reported in game-based learning (around 22%) was single player, followed by collaborative play (around 20%); approximately 10% of the papers addressed competitive gameplay purposefully, 10% reported on games affording both single-player and multiplayer modes, and other papers did not report the gameplay modes. This review also found that the studies on collaborative play reported mixed results.

Designing both single-player and multiplayer versions of a game and shifting the game scoring rules to frame collaboration and competition was a frequent strategy of the previous studies investigating modes of gameplay. For example, Plass et al. (2013) examined a drill-and-practice game (called *FactorReactor*) to practice and automate arithmetic skills that was designed with three modes of play. In the single-player version, one played individually and was encouraged to get the best score possible. In the multiplayer, or social play, version, one played with a partner in front of a computer with two controllers, with a collective score computed and displayed based on the combined behaviors of the pair of individuals (to encourage peer collaboration) or two individual scores computed and displayed (to encourage competition against each other). The results of the study indicated that although both modes of social play increased affective outcomes such as situational interest and game enjoyment, only the competitive mode resulted in increased in-game performance compared with individual play, whereas collaborative play reduced in-game performance. Gameplay mode had no effect on arithmetic fluency. The finding on the lack of effect of gameplay modes on content-relevant learning outcomes was replicated in a later study by Tsai et al. (2015) that examined individual and social competitive-play versions of a digital board game teaching energy-related conceptual knowledge. Tsai et al. (2015) reported that gameplay mode had no effect on either knowledge acquisition or participation perception.

In two other studies, the games enabled learners to choose whether to play collaboratively or competitively. The study by Pareto et al. (2012) examined a two-player card game that supported conceptual understanding of basic arithmetic and gave students the choice of playing with or against each other. Notably, the game also provided a computer-controlled teachable agent for each player, and hence a pair of students could choose to play collaboratively with or competitively against each other, or collaborate as a pair to play against the teachable agents. The study found that students in pairs often shared game-playing insights whether they collaborated or competed, and in their self-invented modes of play collaboration was frequently mixed with competition. The study reported that the gaming group outperformed the control group in both the math knowledge test and in development of positive math attitudes. It also suggested that the various ways the students chose or discovered to play the game were important for their gaming motivation and game-based insights. Similarly, Siu, Zook, and Riedl (2014) examined a two-player game that supported commonsense knowledge collection and afforded a self-chosen mode of play in addition to collaborative or competitive play. In collaborative play, players played as a pair and their gaming score was based on both choice correctness and choice agreement between partners; in competitive play, players played against each other by not only maintaining their own score but also minimizing the opponent's score; and in self-chosen play, the player could choose either the collaborative or the competitive mode of play. The study's result, unlike that of Pareto et al. (2012), suggested that giving players the choice of gameplay modes appeared to be a distraction, reduced their in-game performance, and did not matter because players generally picked a consistent mode of play. The study did not find a significant difference in learning outcomes between collaborative and competitive play, though competitive play was more engaging than collaborative play.

In general, the aforementioned studies indicated that modes of gameplay executed via the scoring rule would mediate affective outcomes or game skill development more than content-related learning outcomes. Importantly, in these studies, because the modes of play were solely framed by the scoring rule, the primary game action generally remained the same (e.g., individualistic puzzle solving) in spite of the different goal structures. This design pattern may explain why gameplay modes framed by scoring rules appeared to affect only motivational responses, since game-based cognitive processes and content-related learning outcomes should usually be activated by game actions (Ke, 2016).

Collaborative gameplay mechanism Among the studies reviewed, only two examined collaboration as an intrinsic part of the core game action. Hung, Young, and Lin (2015) examined a multiplayer crossword Fan-Tan card game for language learning, in which group interdependence was an essential feature of collaboration that was intrinsically integrated into the primary game action. When competing with other groups in the game, members within a group were positively reliant on each other through resource exchange, synchronous interaction with peer monitoring, and task interdependence in cobuilding the word map. The study found that collaborative gaming, compared with collaborative paper-and-pencil drilling (the control condition), better promoted learning achievement for low-achieving students, while there was no difference between the two conditions for high-achieving students. In addition, student groups in collaborative gaming had discussions that were more active and knowledge constructive than those of students in the control condition.

Hummel et al. (2011) examined the integration of scripted collaboration as the core gameplay action for a multiplayer serious game on water management. Through structured role-play, investigative inquiry-oriented interactions, and collective decision making, collaboration was intrinsically integrated into the core game mechanics. By comparing participants' problem-analysis performance before and after gameplay, the study reported that the scripted collaborative gameplay promoted game-based learning of complex skills.

The aforementioned two studies consistently reported the learning effectiveness of game-based collaborative learning, indicating that purposeful integration of salient prerequisites for collaborative learning, such as positive interdependence and a script or structure for the collaboration process, into the core game mechanics is applicable and warranted.

Summary

The following patterns on the effectiveness and boundary conditions of collaboration and competition in game-based learning have emerged from the findings of prior research:

- Collaboration and competition were frequently designed and examined as a social interaction context and an evaluation and recognition dimension of the game-based learning environment, mainly meant to make different types of achievement goals salient and to elicit higher-level and qualitatively desirable patterns of motivation (e.g., a mastery orientation). Correspondingly, the previous findings provided more evidence for their impacts on affective responses than cognitive learning processes and outcomes of game-based learning. As some scholars (Mullins, Rummel, & Spada, 2011; Plass et al., 2013) have argued, modes of gameplay appeared to influence motivational responses to gaming, fluency of gameplay, or game-relevant skills rather than content fluency or learning transfer.

- The advantage of collaboration for game-based learning compared to competition and individuality was evident only in the presence of positive interdependence, a scripted collaborative task highlighting information articulation and organization, and a below-average learner group.
- The role of competition in game-based learning is generally related to situational interest (or game enjoyment) and in-game performance or game-relevant skills. The research and evidence on its impact on game-based content learning processes and outcome is still lacking.
- A mixture of collaboration and competition in gaming for learning was common and appeared to be well received, though providing learners with the autonomy to choose and shift gameplay modes during gaming had mixed results.
- Frequently, collaboration and competition processes were framed solely by changing the external reward or internal game scoring rules, which were not necessarily aligned with the core game or game-based learning actions. The nature of the core game-based learning task or action was still individualistic in spite of a collaborative or competitive social context.

Based on the previous studies' empirical findings, one analytical speculation is that the targeted game-based learning actions (e.g., sense making for conceptual understanding versus procedural problem solving for fluency in rule identification and application), game mechanics (e.g., primary gameplay actions with rules), and the design of gaming or game-based learning contexts (e.g., goal structures, social interaction contexts, external learning supports, and duration and frequency of gaming) all compose a complex and dynamic activity system that frames and mediates the integration of collaboration and competition in game-based learning. Various factors in the speculated activity system, as well as learner differences, would independently and interactively affect the role and impact of collaboration and competition on game-based learning engagement and performance.

Implications of Prior Research

Theoretical Implications

The previous study findings on collaboration and competition in game-based learning generally support the self-determination and cognitive evaluation theories on the regulation of environmental events and structures on intrinsically motivating learning activities. They confirm the sociocultural perspective on the interdependence of social and individual processes in knowledge co-construction. They have also provided empirical evidence on whether collaboration could reduce the intrinsic cognitive load of a learning task.

Self-determination theory (SDT) and cognitive evaluation theory of motivation (Deci & Ryan, 1985; Ryan & Deci, 2000) argue that social and environmental events and structures can facilitate or forestall intrinsic motivation by supporting or thwarting the psychological needs for autonomy and competence. SDT claims that intrinsic motivation can be "catalyzed … in conditions that conduce toward its expression" (Ryan & Deci, 2000, p. 58). More specifically, cognitive evaluation theory contends that interpersonal and other environmental events and structures (e.g., rewards, communications, and feedback) that are conducive to feelings of both competence and autonomy during action can enhance intrinsic motivation of that action. In comparison, an expected tangible reward or threat made contingent on task performance, such as competition pressure, may undermine or diminish intrinsic motivation, because people experience them as external controllers that undermine their sense of autonomy (Deci & Ryan, 1985; Ryan & Deci, 2000). In support of this contention, Plass et al. (2013) and Ke (2008) reported that participants' engagement with an intrinsically motivating activity (e.g., gaming) can be mediated by the extrinsic reward structures of collaboration, competition, and individuality. Particularly, Chen and Law (2016) reported that collaboration, in comparison to competition and individuality, may reduce or undermine perceived autonomy and competence derived from gaming.

Extrinsically regulated activities can reinforce higher levels of engagement, satisfaction, and achievement *when the external prompt or regulation is internalized or identified with*. Specifically, Ryan and Deci (2000) claimed that the primary reason people perform extrinsically motivated (or prompted) activities is that these activities are valued by others to whom the people feel connected. This implies that the grounds for facilitating internalization of external prompts is to provide a sense of connectedness or relatedness to the group. This theoretical speculation helps to explain the previous findings on the significance of positive group dynamics and the design of positive interdependence in collaboration as a social or external event (Chen et al., 2015; Hung et al., 2015; Peng & Hsieh, 2012). Specifically, Hung et al. (2015) found that intragroup collaboration coupled with intergroup competition would reinforce positive interdependence in game-based learning. Prior research suggested that it is also warranted for stimulating positive interdependence via inherent game mechanics. Game actions and rules that allow the *combination* of collaboration and competition (e.g., Pareto et al., 2012), compared with those requiring the selection of a single context (e.g., Siu et al., 2014), increase student motivation and learning outcomes.

SDT also argues that students will more likely internalize or adopt an external goal if they have a sense of competence and autonomy with it (hence they inwardly grasp its meaning). Thus, support for competence (e.g., offering optimal challenges and efficacy-relevant scaffolding or feedback) and for autonomy (e.g., providing a meaningful rationale) will facilitate goal internalization. This speculation is aligned with the findings that scripting (to provide a meaningful rationale for collaboration) and scaffolding or structure (for more competence in cognitive elaboration) will strengthen the positive effect of collaboration for game-based learning, and that elaborative feedback (in spite of gaming mode differences) promotes knowledge construction in game-based learning (e.g., Chen & Law, 2016; Hummel et al., 2011; Tsai et al., 2015; Van der Meij et al., 2011, 2013).

Prior research found that individual learners differed in their interactions with alternative gaming modes and structures for learning, which suggests that the process of internalizing external goal structures is mediated not only by the supportive external contexts but also by characteristics of individual learners. The studies by Chen et al. (2015), Ke and Grabowski (2007), and ter Vrugte et al. (2015) all reported that individuals who vary in prerequisite knowledge level and learning needs will experience a sense of competency, autonomy, and relatedness differently during extrinsic regulated activities and hence may or may not internalize those prompts or goals, which in turn influences their participation behaviors and learning achievements.

In general, collaboration, competition, and individuality are used more as external events or structures for motivation in game-based learning. Hence, they tend to mediate the affective outcomes, such as enjoyment, situational interest, self-efficacy, and positive coping (persistence with attempts), more directly and immediately than game-based learning achievements, especially when the gaming duration is short and only instant outcomes are measured (Ke, 2008; Plass et al., 2013).

Alternatively, collaboration, consisting of debriefing and cognitive elaboration via peer interactions, has been designed and examined as a cognitive process of inter-subject meaning making (Vygotsky, 1980) or a scaffold for handling cognitive load demands during complex problem solving (Kirschner, Paas, & Kirschner, 2009). Collaboration is used because of its stimulating effect on verbalization, which is hoped will stimulate information articulation and organization. Yet Chen et al. (2015) and Van der Meij et al. (2011, 2013) reported that the epistemic quality of game-based, collaborative verbalization or discussions varied—certain group discussions may focus on superficial gaming skills or strategies rather than learning or content-related skills or knowledge development. Scripting for interaction (e.g., Hummel et al., 2011), group dynamics, and personality traits of individuals (e.g., SES or learning-disadvantaged students; see Ke & Grabowski, 2007) all moderate the quality and outcomes of game-based, collaboration-stimulated verbalization. As highlighted by Sung and Hwang's (2013) study, focusing students' collaboration on knowledge co-construction rather than gaming is warranted.

According to sociocultural learning theory, participating in a structured group activity that emphasizes cognitive elaboration is a critical aspect of making meaning. Based on cognitive load theory, dividing the processing of information across individuals is useful only when task complexity increases and the cognitive load is high, whereas under low load conditions, an individual can adequately carry out the required processing activities, and the costs of information recombination and coordination in a group become substantial and less rewarding (Kirschner, Paas, & Kirschner, 2009). These theoretical perspectives were validated by the empirical findings that the role of collaboration in game-based learning is undermined when cognitive elaboration is lacking or dispensable among players during collaborative gaming (e.g., Ke, 2008; Ke & Grabowski, 2007; Plass et al., 2013; Van der Meij et al., 2011) and when the cognitive challenge of the game task is low (e.g., Hung et al., 2015; Siu et al., 2014).

Practical Implications for the Design of Game-Based Learning

A salient theme derived from the findings and the preceding discussions is that collaboration and competition in game-based learning should be designed as intrinsically motivating activities, or external structures that learners will voluntarily identify with during game-based learning. When arranged as contextual events (e.g., grouping or rewarding structures) of educational gaming, collaboration and competition become extrinsic regulations that are subordinate to or even incoherent with the motivating properties of a learning-game action. By integrating them as an inherent facet of the primary game action (e.g., a collaborative inquiry with scripted role-play, a realistic science and design competition), a game-based learning process will be intrinsically collaborative or competitive, thus saving an extra undertaking of making learners internalize or coordinate the external goals with the internal game mechanics.

To stimulate positive interdependence for learning while satisfying the motivational needs of diverse individual learners, a combination of collaboration, competition, and even individuality should be considered when designing the primary game actions and scoring and rewarding rules in a game-based learning system. Positive interdependence can be purposefully framed not only by the scoring rules but also via the structure of the task, the support of roles, and backdrop scripting of the manner of interaction, as illustrated by the studies of Hung et al. (2015) and Hummel et al. (2011). Apart from the structured mixture of intragroup collaboration with intergroup competition documented in prior research, game mechanics that enable learners to voluntarily explore and take on multiple modes of gameplay (e.g., playing individually or collaboratively against peers or a computer agent) have been found to be versatile and engaging (e.g., Pareto et al., 2012).

Prior research has confirmed that just placing individual players in a group will not guarantee game-based cognitive elaboration and knowledge co-construction. The nature of game-based interaction and verbalization is independently and interactively influenced by core game design features, the nature of learning actions framed by the game mechanics, and the game's implementation or contextual aspects. Hence, the process of designing collaboration as a game-based learning support should be systematic, in which the targeted level of learning outcome (conceptual understanding versus procedural skill development), the type and duration of game-based learning action (e.g., collaborative meaning making for longer gaming duration versus accelerated problem solving), and the design of collaboration (e.g., collaborative knowledge engineering versus postgaming debriefing) should be aligned with each other.

Future Research

Current research on collaboration and competition in digital game-based learning has frequently manifested them as the external grouping or activity structure that aims to regulate game-based learning processes by changing the performance rewards or scoring rules. Such a conceptualization of collaboration and competition highlights them as the construct of extrinsic regulation (or motivation) of the internal game flow or as the social interaction context moderating game-based information articulation and coordination. Research depicting collaboration or competition as an inherent feature of game-based learning action or as a cognitive strategy of gameplay is still lacking. Besides, when examining the role of collaboration and competition as external events of game-based learning, the previous studies generally lack an examination of the interaction between these external events and the internal game mechanics. For example, will inconsistency between external goal structures and the mode of primary game actions affect game-based learning engagement and outcomes? Studies that purposefully align goal structures of external learning activities with the internal modes of gameplay, whether collaborative, competitive, or individualistic, are warranted.

Most current efforts in designing or examining game-based collaboration and competition for learning are segmented. Yet a potential conclusion from those research efforts is that game-based learning is a complex and dynamic activity system in which the targeted game-based learning actions, game features, and game implementation contexts will coframe and influence the emergence and consequence of collaboration and competition. Hence, future research should employ a systematic analytical framework when examining collaboration and/or competition as a facet within the game-based learning system or explore and compare the relative effectiveness of integrating collaboration and competition into different sectors of this activity system. Longitudinal research efforts and iterative design experiments that refine and examine the design and role of collaboration and competition in relation to other facets of the game-based learning system are particularly desirable.

There is evidence suggesting that learner-initiated collaboration or competition during game-based learning is more prominent than imposed collaboration or competition. Empirical research describing or analyzing the prerequisite and consequential events of voluntary learner participation in game-based collaboration or competition for learning should be informative. Since learner differences moderate the role and impact of collaboration and competition for game-based learning engagement and performance, a potential design strategy and research direction may be to adapt the level and mixture of collaboration and competition dynamically based on individual learners' needs and in-game performance. The level and type of competition as a form of optimal challenge, as well as the dosage and protocol of collaboration as a form of learning or learner support, can be altered adaptively based on the tracking and mining of game-based learners' in-game affective and cognitive learning states.

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14 Emerging Design Factors in Game-Based Learning: Emotional Design, Musical Score, and Game Mechanics Design

Shashank Pawar, Frankie Tam, and Jan L. Plass

Introduction

For many of the design factors described by the model of game-based learning (Plass, Homer, & Kinzer, 2015; Plass, Homer, Mayer, & Kinzer, chapter 1 in this volume), sufficient research exists to allow design recommendations for game designers. These factors include instructional support, feedback, and coaching (Lester, Spain, Rowe, & Mott, chapter 8 in this volume), self-regulation and reflection (Taub, Bradbury, Mudrick, & Azevedo, chapter 9 in this volume), adaptivity and personalization (Plass & Pawar, chapter 10 in this volume), narratives (Dickey, chapter 11 in this volume), multimedia design principles (Nelson & Kim, chapter 12 in this volume), and social mode of play (Ke, chapter 13 in this volume). However, for a number of other design factors described in the model, only a small body of research in the context of game-based learning exists. Three of these emerging factors are discussed in this chapter, including emotional design, the game's sound and musical score, and game mechanic design. We discuss these constructs and summarize the limited research available on these design factors in the context of game-based learning. Additional emerging factors are discussed in Tam and Pawar (chapter 15 in this volume).

Emotional Design

Playing video games is an emotional experience (Isbister, 2016; Plass et al., 2015). When playing a game, players' emotions are influenced by various game elements, as described by Loderer, Pekrun, and Plass (chapter 5 in this volume). Emotional design is the practice of identifying these elements and utilizing them to induce a range of emotions in players. In the realm of video games and learning, the goal of emotional design is to induce emotions to enhance learning outcomes (Plass & Kaplan, 2015).

Summary of Construct of Emotional Design

The idea of designing media to induce positive emotions has been around for a long time (Norman, 2004), but research on its application for learning is still sparse. Emotional design is "the use of a range of design features with the goal to impact learners' emotions to enhance learning" (Plass & Kaplan, 2015, p. 138). Virtually all game design features can be used to induce specific emotions in learners. This includes the visual representation of information, the design of interactions in the form of game mechanics, and the game sound.

The concept of emotional design for learning is based on research showing the relation between cognition and emotion (Isen, Shalker, Clark, & Karp, 1978; Izard, 1993). These findings show a causal link between emotional states and cognitive processes such as attention, perception, and memory (Derryberry & Tucker, 1994; Isen, Daubman, & Nowicki, 1987; Isen et al., 1978; Izard, 1993, 2007; Lewis, 2005). The results show that various cognitive processes are enhanced when a learner is in a positive emotional state. This has led to the development of theories describing how emotions affect learning. The control-value theory of achievement emotion describes the antecedents and effects of emotions experienced by learners (Loderer et al., chapter 5 in this volume; Pekrun, 2006; Pekrun & Stephens, 2010). In the context of learning with digital media, the integrated cognitive-affective theory of learning (ICALM) provides a theoretical foundation for the effect of emotion on learning. This theory posits that emotions play a central role in information processing to create mental models for learning. It suggests that learners select, organize, and integrate information through the reciprocal relation between cognitive and emotional processes, and hence emotions, cognition, and learning are inherently connected (Plass & Kaplan, 2015).

The ICALM theory is backed by empirical evidence investigating the affordances of media elements to induce emotions and, as a result, to improve learning outcomes (Mayer & Estrella, 2014; Plass, Heidig, Hayward, Homer, & Um, 2014; Plass & Kaplan, 2015; Um, Plass, Hayward, & Homer, 2012). This has led to the development of the integrative model of emotional foundations of GBL (EmoGBL), which describes the mechanisms for how learning processes and emotion interact to develop specific learning outcomes (Loderer et al., chapter 5 in this volume). EmoGBL describes proximal antecedents of emotion, such as appraisals of the situation and of the self, emotional transmission from human peers, virtual peers, teachers, or other game features; distal antecedents, such as achievement goals and beliefs; and the emotional design of the game-based learning environment. In our discussion of emotional design for learning, we focus on how specific game elements evoke emotions for improving learning outcomes.

Emotional Design in Games for Learning

Various game elements have a strong influence on players' emotional states. Game characters and game environments are known to be effective in this regard (Anderson et al., 2017; Isbister, 2016; Riva et al., 2007). *Game characters* are intentional agents that take actions in a game environment. They represent either players or nonplayer characters (NPCs). Game characters have a strong influence on emotional states of players, as they can convey emotions through facial expressions (Plass et al., in press), postures (Clavel, Plessier, Martin, Ach, & Morel, 2009), and movement (Fagerberg, Ståhl, & Höök, 2003). Different design features of game characters influence their ability to induce players' emotions. These include static features, such as shape, color, and dimensionality (Mayer & Estrella, 2014; Park, Knörzer, Plass, & Brünken, 2015), and dynamic features, such as expressions, postures, gestures, and movement (Clavel et al., 2009; Dittmann, 1987; Fagerberg et al., 2007; Plass et al., in press). Multiple studies have investigated the effect of manipulating shapes and colors of characters on emotion induction (Mayer & Estrella, 2014; Plass et al., 2014; Plass & Kaplan, 2015; Um et al., 2012). Results from these studies have shown that game characters with round shapes and warm colors lead to higher emotion induction and better learning outcomes. In addition to shape and color, the dimensionality of game characters also affects emotion induction. A study conducted by Hovey, Pawar, & Plass (2018) found significant effects when comparing differences in emotional arousal from 3-D versus 2-D characters. In this study, participants played the same learning game in immersive 3-D and 2-D environments. Results showed that participants experienced higher emotional arousal in the 3-D version than in the 2-D version, but these findings have not yet been linked to learning outcomes.

Dynamic features of game characters, such as their expression, posture, and movement, also play an important role in emotional design. Game characters can convey their emotional state through *facial expressions* and in turn can generate an affective response in players (Paiva et al., 2004). In a study conducted by Plass et al. (in press), participant ratings of game characters expressing happy and sad emotions were compared to the ratings of the same characters expressing neutral emotions. Results showed that characters with happy and sad expressions were rated as more emotionally inducing than characters with a neutral expression (Plass et al., in press). These findings illustrate the affordance of game characters to influence player emotions using character expressions. Game characters can also convey their emotions through body language. The *body posture* of characters, when paired with facial expressions, conveys their emotional state (Clavel et al., 2009). Some studies have shown that body postures convey the intensity of felt emotions (Dittmann, 1987), while others have shown that they provide a context for interpreting facial expressions and verbal cues of emotions (Harrigan, Rosenthal, & Scherer, 2008). These findings suggest that character postures can support other emotional design features. In addition to postures, *body movement* is also an important factor in nonverbal displays of emotions. The manner of movement can ascribe specific emotional states to a game character and hence frame players' emotional expectations. A study by Fagerberg, Ståhl, and Höök (2003) provides preliminary support to this claim by identifying three underlying dimensions of movement—shape, effort, and valence—associated with emotional expressions. In this study, researchers used Laban and Lawrence's (1974) framework of movement analysis to categorize emotions into groups with specific movement characteristics. For example, anger was associated with spreading, rising, and advancing movements, while sadness was conveyed through enclosing, descending, and retiring movements (Fagerberg et al., 2003). These outcomes indicate that body movement is another useful feature for emotional design in games.

Game environments are virtual spaces that host gameplay. All game characters and game events act in the context of these spaces. Because game environments situate players and characters in a virtual world, they play an important role in influencing players' emotions. This phenomenon was investigated by Riva et al. (2007), who studied the effect of three virtual environments—anxious, relaxing, and neutral—in inducing emotions. The researchers manipulated environmental features such as shape, scenery, and lighting to elicit different emotions, and found significant differences in ratings of sadness, anxiety, and happiness for the different environments. These results suggest that different features of game environments, such as shape, scenery, and lighting, can be designed to evoke distinct emotional states in players (Riva et al., 2007). The *shape* of an environment can be considered the architecture of the play space. Studies have shown that factors such as space geometry and ceiling height can influence information processing, emotions, and cognitive processes (Meyers-Levy & Zhu, 2007; Shemesh et al., 2017). Similarly, *scenery* plays an important role in setting the context of the environment. Research comparing player affect and stress in natural and urban virtual environments has found that natural environments facilitate higher levels of positive affect and lower levels of stress (Anderson et al., 2017). The *lighting* of the game environment also influences emotional states of participants. The effect of environmental lighting has been studied extensively in the real world (Knez, 1995; Knez and Kers, 2000; Kumari & Venkatramaiah, 1974). Research has shown that higher luminescence leads to increased physiological arousal (Kumari & Venkatramaiah, 1974). The color of lighting has also been found to induce different emotional states in participants. Knez (1995) found that warm (reddish), bright light and cool (bluish), dim light induced positive moods. These findings can be extended to virtual game environments to evoke desired affective states. So far, research on effects of lighting in virtual environments has been studied in combination with sound, music, and texture manipulations (Riva et al., 2007), making it difficult to associate emotional differences to lighting alone.

Future Directions for Research on Emotional Design

The importance of emotions in cognition and learning has been established by empirical research (Izard, 1993, 2007; Pekrun & Stephens, 2010) and by theories such as CVT, ICALM, and EmoGBL. Many fields, including product design, advertising, and consumer marketing, have incorporated these findings into their design processes (Bagozzi, Gopinath, & Nyer, 1999; Demirbilek & Sener, 2003; Norman, 2004). Although emotions are playing an important role in game-based learning, there is only preliminary research on emotional design, linking methods of inducing emotions to corresponding learning outcomes (Mayer & Estrella, 2014; Plass et al., 2014; Plass & Kaplan, 2015; Um et al., 2012). These studies have investigated a limited number of visual aspects of emotional design, such as game characters and game environments. As games include various other elements that can be utilized for evoking emotional responses in users, research should explore the effect of additional game design elements. For example, the effect of audio design and musical scores, or interaction design and game mechanics, on emotion elicitation should be investigated in the context of game-based learning. Furthermore, with the emergence of technologies such as virtual reality, augmented reality, and mixed reality, approaches to emotional design that take advantage of the affordances of these media should be investigated. As a long-term goal, emotional design should be integrated as a fundamental feature in the design of game-based learning environments.

Musical Score

The musical score of a game is comprised of the sounds and music used as auditory stimuli in the game. The arousal and mood hypothesis (Thompson, Schellenberg, & Husain, 2001) suggests that music is a stimulus that influences listeners' arousal and mood, which then affect performance on cognitive tasks. Studies have suggested that arousal and valence, the two dimensions of emotions in Russell's (1980) circumplex model of affect, can influence performance on various cognitive tasks, including creative problem solving (Ashby, Isen, & Turken, 1999; Ilie & Thompson, 2011), arithmetic (Hallam, Price, & Katsarou, 2002), information integration (Estrada, Isen, & Young, 1997), decision making (Isen & Means, 1983), and spatial ability (Husain, Thompson, & Schellenberg, 2002). It has been argued that musical tempo is associated with influencing arousal, while musical mode primarily affects mood (Husain et al., 2002). In this section, we explore the impact of music on learners in different environments.

Summary of Construct of Musical Score

In our definition, the musical score in a game includes all sounds and music used by a game. The most noticeable aspect is usually the game's sound track, but environmental sounds and sounds in response to player actions are included as well. These sounds can serve multiple objectives. On an affective level, they can induce emotions in the player, which link to their motivational objectives. A game's music and sounds can also have cognitive objectives, such as providing information to players, giving cues, and providing feedback (Plass et al., chapter 1 in this volume).

Music in computer games has evolved from the rudimentary sounds in the early days to music today that is written specifically for games, with the music resembling virtually every existing style (Munday, 2007). Game music incorporates various musical styles, including gothic, classical, rock, new age, jazz fusion, and even its own invented style (Belinkie, 1999). Game music is usually precomposed and recorded by game composers, though in some cases procedurally generated music is used (Collins, 2009).

Munday (2007) identified three main functions of game music: environmental, immersion, and diegetic. For the *environmental* function, Munday (2007) suggests that game music enriches players' perception of the game world. Scholars have argued that game music provides nonvisual information, including game theme and state (Whalen, 2004), ascribes meaning to game objects and environment (Chion, 1994), and provides crucial information for players to interpret the game environment (Cohen, 2000).

Concerning the *immersion* function, Munday (2007) argues that music is a crucial factor in influencing a player's sense of immersion. Sanders and Cairns (2010) suggest the choice of music can increase or decrease a player's sense of immersion. A player's enjoyment of music is suggested as one of the major factors in determining the player's level of immersion. Whalen (2004) contends that game music that complements the game's narrative may encourage immersion.

Finally, for the *diegetic* function, Cohen (2000) suggests that music adds meaning to the game story by confirming visual information and resolving ambiguity. Whalen (2004) argues that game music with different rhythms and tempos helps players identify safety and danger stages in the game narrative.

Music and Affect

Music can be used as an agent to induce emotion change, which can lead to performance improvements (Thompson et al., 2001). In a controversial line of inquiry, research found increases in listeners' performance on measures of spatial abilities after listening to music composed by Mozart (Rauscher, Shaw, & Ky, 1993). Thompson et al. (2001) conclude that the "Mozart effect" is an example of enhanced performance induced by positive mood and arousal. According to the arousal and mood hypothesis, this effect is not specific to Mozart's music or a specific musical stimulus but can be found with other music that is similarly engaging or creates pleasant stimuli. Nantais and Schellenberg (1999) demonstrated that listening to a short narrated story can also enhance spatiotemporal task performance. They concluded that preference is a crucial factor in influencing arousal and mood. The condition preferred by a learner enhances arousal and mood and hence increases performance. The arousal and mood hypothesis also applies across different cognitive tasks, age groups, and cultures. Schellenberg, Nakata, Hunter, and Tamoto (2007) found that adolescents performed better on an IQ subtest after listening to up-tempo music, while five-year-old Japanese children became more creative and energetic with their drawings after being exposed to familiar children's songs. However, extreme levels of arousal and negative mood can inhibit performance. Yerkes and Dodson (1908) suggest an inverted U-shaped relationship between arousal and performance. When arousal levels are either very high or very low, performance is impacted negatively.

Tempo, Mode, and Affective States

The influence of music's tempo and mode on emotional state has been examined extensively. Musical tempo has been argued to be the most important factor that influences a listener's affective state (Hevner, 1937). Up-tempo music may enhance performance, but it could also act as a stressor (Mayfield & Moss, 1989). Some studies have shown that music in major mode is associated with happiness, while minor mode is associated with sadness (Mayfield & Moss, 1989). Hevner (1937) suggests that minor mode is associated with "sad and heavy" and "dreamy and sentimental," while major mode is associated with "happy and bright" and "exciting and elated" emotional states Husain, Thompson, and Schellenberg (2002) argue that tempo and mode affect enjoyment. Higher enjoyment is experienced with fast tempo in music in major mode, while in music in minor mode, there is slightly more enjoyment with slower tempo.

Music and Performance in Games

There is some research investigating the effect of music on performance in games. Research found, for example, that low-arousal music leads to faster lap times in a driving game than high-arousal music (North & Hargreaves, 1999). The researchers suggested that high-arousal music has a higher cognitive load demand than low-arousal music and hence affected driving performance. Cassidy and Macdonald (2010) argue that music preference and tempo are crucial factors influencing performance in a driving game. They conclude that players who listen to self-selected music and high-arousal music perform better than players who listen to experimenter-selected music and low-arousal music. On the other hand, there are mixed results from participants memorizing facts in a virtual learning environment with and without background music (Fassbender, Richards, Bilgin, Thompson, & Heiden, 2012). Participants using a semicylindrical three-projector display system performed better with background music than without it. However, participants using a three-monitor display system performed better without background music. Cognitive load and familiarity with the technology are the potential explanations for these results.

Future Directions for Research on Musical Score

There is a paucity of research dedicated to the study of music in the context of games for learning. Future research should address questions regarding music for such games in multiple areas. One question to investigate is how different types of music influence a learner's behavior in different types of learning games, such as games with different learning goals and of different genres. Research has found that learners behave differently under different conditions—with music that varied in tempo and mode, without music, and with self-selected music. We need a better understanding of the factors and mechanisms that influence learners' behaviors under these different conditions. We also need to understand the role of learners' music preferences and their impact on their learning behavior. Lastly, future research should be conducted with participants with a broader range of demographic attributes.

Game Mechanics

Game mechanics are tools for gameplay (Fabricatore, 2007). Salen and Zimmerman define the mechanic as "the experiential building blocks of player interactivity. It represents the essential moment-to-moment activity of players, something that is repeated over and over throughout a game" (Salen and Zimmerman, 2004, p. 317). Mechanics allow players to receive information and interact with the environment to produce output. The game *Angry Birds*, for example, features a sling mechanic that allows the player to hurl birds at standoffish pigs. The game *All You Can E.T.* features a shooter mechanic that feeds hungry aliens with either cupcakes or milkshakes (see figure 14.1).

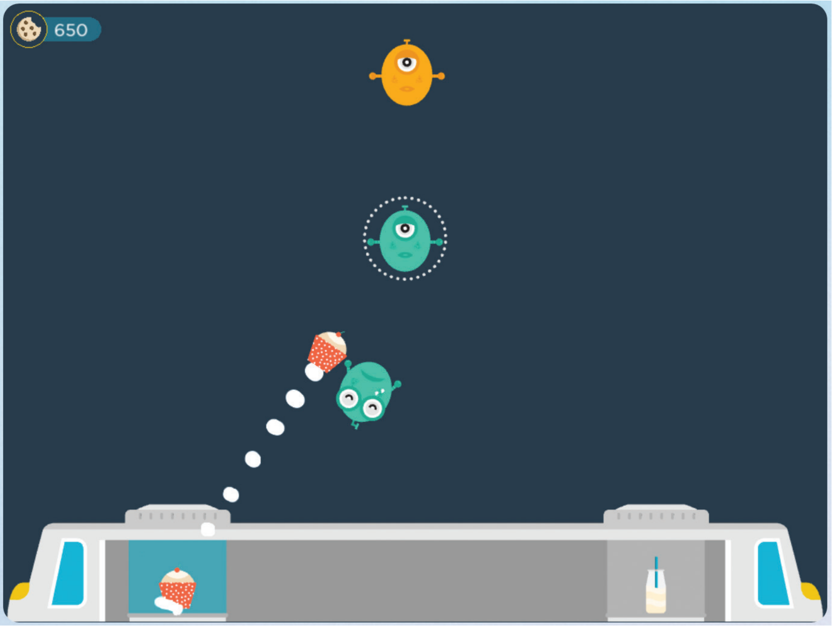

Figure 14.1
Shooter mechanic in the game *All You Can E.T.* (CREATE, 2015).

According to the mechanics, dynamics, and aesthetics (MDA) framework, the game mechanic is an essential component that determines game dynamics and the aesthetic experiences of games (Hunicke, LeBlanc, & Zubek, 2004). Game scholars, researchers, and designers have provided a variety of definitions of game mechanics. Salen and Zimmerman (2004) describe core game mechanics as activities that players perform repeatedly. Core game mechanics allow players to make meaningful decisions and hence create meaningful gameplay experience. Hunicke, LeBlanc, and Zubek (2004) contend that game mechanics are defined by game actions, behaviors, and control mechanisms. Sicart (2008) further suggests that game mechanics are actions carried out by players in the game world with the goal of interaction, where the actions are constrained by game rules or the game world. In this section, we explore different aspects of mechanics in games for learning and their effects on learners.

Summary of Construct of Game Mechanics

The high quality and educational effectiveness of the learning experience are two of the most important goals of learning-game design. Games for learning motivate and engage learners in order to achieve these goals. Plass et al. (2015) argue that a game mechanic is a crucial game design element that allows games to engage learners at multiple levels, including affective, behavioral, cognitive, and sociocultural domains. Scholars have suggested that game mechanics are a determining factor in promoting learning in educational games (Aleven, Myers, Easterday, & Ogan, 2010; Gunter, Kenny, & Vick, 2008; Plass et al., 2015). There are two important considerations for designing effective game mechanics for educational games. First, game mechanics should incorporate principles of the learning sciences (Aleven et al., 2010; Gunter et al., 2008; Homer & Plass, 2014). By incorporating such principles when designing game mechanics, games can support learning that is aligned with findings of the learning sciences and related theories (Aleven et al., 2010). Second, the game mechanic should be integrated with the learning content (Aleven et al., 2010; Gunter et al., 2008; Habgood, Ainsworth, & Benford, 2005). When learning content and game mechanics are aligned, learners' interest is higher, and learning outcomes are more likely to be achieved. Such an alignment also allows learning and gameplay to progress seamlessly without interrupting the flow of the games (Gunter et al., 2008).

Game Mechanics and Learning Mechanics

In order to describe the specific requirements for mechanics in games for learning, scholars introduced the concept of *learning mechanics* (Plass, Homer, Kinzer, Frye, & Perlin, 2011). While game mechanics describe the major building blocks of play activities, learning mechanics describe the major building blocks of learning activities (Plass & Homer, 2012). For example, a learning mechanic in *Crystal Island* (Lester et al., chapter 8 in this volume) involves communicating with game characters to collect information.

There are two major characteristics of learning mechanics. First, they are not playable mechanics but rather are design patterns of learning interactions, and need to be instantiated as game mechanics (Plass et al., 2011). Different game mechanics can be instantiated from the same learning mechanic, depending on the target audience, game genre, context, and learning goals. In our example, how the learner communicates with game characters can be implemented in different ways. They may simply walk up to them and talk to them, they may have to communicate in writing, or they may use a communication device. Second, design of learning mechanics should be grounded in the learning sciences (Arnab et al., 2015; Plass et al., 2011). This theoretical basis of learning mechanics allows game designers to implement game mechanics that can facilitate learning as well as gameplay (Plass et al., 2011).

The most important function of game mechanics in educational games is to facilitate learning. Meaningful learning activities are introduced to learners when appropriate game mechanics are implemented based on learning mechanics. This can be done in many ways. For example, Arnab et al. (2015) contend that game mechanics should allow experiential learning during gameplay. Game mechanics should help learners acquire new knowledge or skills through interactions in the game world.

Game Mechanics and Learning Mechanics Design

Learning mechanics define the essential learning interactions that take place within a game (Plass, Perlin, & Nordlinger, 2010). Learning theories such as situated learning, cognitive apprenticeship, anchored instruction, and many others can be used as foundations when designing learning mechanics. Domagk, Schwartz, and Plass (2010) provide the INTERACT model, an integrated model of interactivity for designing and understanding learning interactions. This model suggests that interactivity should be designed considering affordances related to medium, learner characteristics, motivation, emotion, the learner's mental model, and learner activities. The model describes an interconnected dynamic relationship between learning system and learners. Domagk et al. (2010) argue that this model allows interactivity to be considered and designed holistically in an integrated system context.

Since multiple game mechanics can be derived from a single learning mechanic, it is important to ensure that each implementation of game mechanics is able to meet the learning objectives (Arnab et al., 2015). The evidence-centered design (ECD) framework (Mislevy, Almond, & Lukas, 2003) provides a systematic process to ensure that design of the game mechanics is aligned with learning mechanics to achieve the intended learning goals. Game designers can apply the ECD framework when designing and validating learning game mechanics. The student model in ECD defines variables related to students' knowledge and skill, the task model is for designing tasks to achieve this knowledge and skill, and the evidence model describes what evidence should be collected from students' task performance. Together, these three models can help game designers design game mechanics that provide opportunities for learners to elicit observable evidence of the targeted knowledge and skill for assessing the intended learning goals (Mislevy et al., 2003).

The integration of the game mechanics with learning content has been suggested by several scholars. Gunter et al. (2008) contend that learning content in games should be organized and introduced in a hierarchical structure such as Bloom's taxonomy. Habgood et al. (2005) suggest that learning material should be integrated with game structure, where learners explore the content through game mechanics and gameplay. One of the few studies that investigated this effect was conducted by deHaan, Reed, and Kuwanda (2010). The researchers studied the effect of a learning mechanic in a music video game on cognitive load and vocabulary recall among undergraduate students in Japan. In a yoked design, one group played the game, which involved a mechanic of flipping burgers under time pressure that was unrelated to vocabulary learning. A participant in the other yoked group watched a player on a second monitor but without actively engaging with the mechanics. Results showed that participants in the group that watched but did not play had higher incidental vocabulary learning and reported experiencing lower cognitive load than the players. These results suggest that a game mechanic that is not aligned with the learning objective introduces extraneous cognitive load that hinders learning.

A small number of studies compared different game mechanics and their effects on learning. Plass et al. (2012) designed two versions of a middle school math game with two different mechanics. They found that learners performed better in the conceptual rule mechanic, where players had to specify which rule they would apply to solve a geometry problem of angles in quadrilaterals, than in the arithmetic mechanic, in which they had to provide the numeric response (angle) of the solution. On the other hand, the arithmetic condition generated more situational interest among players than the concept condition (Plass et al., 2012).

Two experiments on mechanics in a simulation for learning compared an exploratory mechanic with a direct instruction mechanic. The exploratory mechanic allowed learners to use sliders as controls to explore a simulation about the ideal gas laws, while the direct instruction mechanic allowed learners to watch videos of the simulation exploration by an expert. The first experiment, using a less complex simulation with only two variables, revealed that the exploratory mechanic was more effective overall for science learning, as shown by a transfer test. The second study, using a more complex simulation with three variables, showed that learners' executive functions determined which mechanic was more effective. Learners with lower executive functions benefited more from the direct instruction mechanic, but learners with higher executive functions benefited more from the exploratory mechanic (Homer & Plass, 2014).

Research by Kinzer et al. (2012) operationalized a choice mechanic by providing learners the choice of selecting their own nonplayer character as an instructional guide in a geometry game. Results suggest that a choice mechanic positively influences learners' learning outcomes, motivation, and in-game performance. Hew, Huang, Chu, and Chiu (2016) concluded that game mechanics such as badges, points, and leaderboards motivate college students to cognitively engage in tasks that are more difficult and to produce a higher quality of artifacts in a gamified learning environment. Learners also became more motivated to participate.

Future Directions for Research on Game Mechanics

Learning mechanics and game mechanics are among the most important elements in the design of engaging and effective games for learning. There are increasing efforts to examine the importance of learning mechanics and game mechanics design in learning games (Arnab et al., 2015; Lameras et al., 2017; Plass et al., 2011; Proulx, Romero, & Arnab, 2017). Arnab et al. (2015) proposed a learning mechanics and game mechanics model for designing and analyzing educational games. Plass et al. (2011) proposed developing a library of learning mechanics and game mechanics to allow game designers to better understand how game mechanics should be designed from learning mechanics. However, there is only limited evidence on the effect of learning mechanics and game mechanics design on learners and learning outcomes.

In future research, the structure of game mechanics should be investigated. Fabricatore (2007) proposes an architectural model of game mechanics. This model describes how game mechanics are made up of two major components, core mechanics and satellite mechanics. Satellite mechanics include enhancement, alternate, and opposition mechanics with the purpose of introducing variations to the core mechanics. Variations in core mechanics can enhance challenges and sustain motivation (Fabricatore, 2007). Future research should investigate how different design patterns of satellite mechanics support and complement core mechanics.

Future research should examine how game mechanics can be instantiated from learning mechanics to maximize educational effectiveness. Plass et al. (2010) argue that games can engage learners in affective, behavioral, cognitive, and sociocultural domains. More research is required to show how game mechanics that foster engagement at affective, behavioral, and sociocultural levels can lead to cognitive engagement that results in improved learning rather than introducing extraneous processing demands. More research needs to investigate how, when, and to what extent the combination of different types of engagements promotes or hinders learning.

We also need a better understanding of how different game mechanics, derived from different learning approaches, influence different learners and their learning outcomes. The findings by Homer and Plass (2014) showed, for example, how the effects of specific mechanics depend on learner variables such as executive functioning skills. Future research should be conducted that includes learners with different characteristics and attributes.

Finally, there are no established processes or design patterns for how to align academic content with game mechanics. Gunter et al. (2008) argue that academic content should be integrated within the game mechanics to allow learners to synthesize and apply the content to create new knowledge to progress to the next higher level. On the other hand, Habgood et al. (2005) suggest that learning content should be represented within the interactions in the game world and delivered through parts of the game that are most fun to play with. The study by deHaan et al. (2010) showed how critical these design decisions are and how game mechanics that are not well designed can hinder learning. Future work should therefore focus on examining design patterns integrating academic content with game structure and mechanics, and their effects on learning.

Conclusion

For several of the design factors described in the model of game-based learning (Plass et al., chapter 1 in this volume; Plass et al., 2015), only limited empirical research exists that investigated design-specific questions as well as the effects design has on learning outcomes in the context of games for learning. In this chapter, we focused on three of these design factors: emotional design, musical score, and game mechanics. Emotional design, which has the goal of facilitating learning by using a range of design factors to induce emotions conducive to learning, has been investigated outside games and been found to have a positive effect on learning. Even though only limited evidence from research with games exists, it is likely that this effect, which has been studied mostly outside games, will be present in games for learning as well. This is especially likely because of the large range of design features in games that can be used to induce emotions. One of these design features is the musical score and game sound, which has been shown to affect learning and performance outside games, and we presented limited evidence that similar effects can be found in games.

Game mechanics, the central building blocks of learner activity in the game, has received surprisingly little attention from researchers. This may be because of methodological problems, as changing the game mechanic often means that an entirely different learning strategy is used. However, the evidence we discuss shows that mechanics have a strong potential to affect learning, and a game's effectiveness may very well hinge on a well-designed mechanic.

Overall, these three design factors are likely to play an important role in the design of games for learning. We therefore made recommendations for future research that should be conducted in order to provide empirical evidence supporting specific design decisions and linking these design factors to learning outcomes.

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15 Emerging Design Factors in Game-Based Learning: Incentives, Social Presence, and Identity Design

Frankie Tam and Shashank Pawar

Introduction

For many of the design factors described by the model of game-based learning (Plass, Homer, & Kinzer, 2015; Plass, Mayer, Homer, & Kinzer, chapter 1 in this volume), sufficient research exists to allow design recommendations for game designers. These factors include instructional support, feedback, and coaching (Lester, Spain, Rowe, & Mott, chapter 8 in this volume), self-regulation and reflection (Taub, Bradbury, Mudrick, & Azevedo, chapter 9 in this volume), adaptivity and personalization (Plass & Pawar, chapter 10 in this volume), narratives (Dickey, chapter 11 in this volume), multimedia design principles (Nelson & Kim, chapter 12 in this volume), and social mode of play (Ke, chapter 13 in this volume). A number of other design factors that are described in the model, however, only have a small body of research in the context of game-based learning. These emerging factors include incentive system design, identity design, and social presence in games. In this chapter, we define these factors and summarize the limited research available on their design and effectiveness in the context of games for learning. Other emerging factors are reviewed by Pawar, Tam, and Plass (chapter 14 in this volume).

Incentive System Design

Games are known for their ability to guide the player's behavior in a way that makes play enjoyable, often by giving incentives to perform a certain task. Incentive systems are considered one of the crucial elements for appealing and motivating games (Garris, Ahlers, & Driskell, 2002; Wang & Sun, 2011). Incentive systems can consist of intrinsic and extrinsic reward elements, such as scores, stars, badges, trophies, and power-ups (Plass, Homer, & Kinzer, 2015). Intrinsic rewards give a player special abilities that can be used in gameplay, while extrinsic rewards do not contribute to gameplay directly. Both intrinsic and extrinsic aspects of incentive systems play an important role in engaging learners. Reward mechanisms that provide a fun and intrinsically rewarding experience may be more useful than extrinsic rewards (Wang & Sun, 2011). According to self-determination theory (Ryan & Deci, 2000), satisfactions of the three basic psychological needs—autonomy, competence, and relatedness—can lead to intrinsically and extrinsically motivated behaviors. Autonomy refers to a sense of volition, competence refers to a sense of efficacy, and relatedness refers to a sense of connection with others and one's community (Ryan & Deci, 2000). Przybylski, Rigby, and Ryan (2010) propose that performance feedback and rewards for achievement in video games have the potential to satisfy these basic psychological needs. Elements of incentive systems have also been applied in nongame contexts to foster motivation and engagement (Mekler, Brühlmann, Tuch, & Opwis, 2015; Muntean, 2011). Rewards provide extra motivation for learners to pursue tasks that otherwise would be less interesting, and they can improve learning outcomes (Pierce, Cameron, Banko, & So, 2003). In this section, we examine the different elements of incentive systems in games and their impacts on learners.

Summary of the Construct of Incentive System Design

Incentive systems consist of a series of design features that provide rewards to players, often with the goal of guiding player behavior. Intrinsic rewards do this by relating directly to the game mechanics and objectives, which can involve giving the player access to special abilities and power-ups, unlocked content, new tools, or hints related to gameplay. Extrinsic rewards, in contrast, are not directly related to the game mechanics and objectives and are usually given in the form of points, scores, stars, coins, and the like. Some rewards could be intrinsic or extrinsic, such as badges or trophies (Plass et al., chapter 1 in this volume).

Incentive systems are vital in game-based learning interventions to provide rewards and performance feedback (McKernan et al., 2015). They can motivate players to replay the game to improve their performance (Garris et al., 2002). Incentive systems that provide feedback may enhance the gameplay experience by allowing players to understand their short-term goals more easily (Wang & Sun, 2011). Rewards may enhance extrinsic motivation, but they may also undermine intrinsic motivation (Deci, Koestner, & Ryan, 1999). Intrinsic motivation is defined as performing an activity for its own satisfaction and enjoyment, while extrinsic motivation is defined as performing an activity in order to attain rewards (Ryan & Deci, 2000). According to cognitive evaluation theory, effects of extrinsic motivation on intrinsic motivation are influenced by a player's perception of the rewards as informational or controlling (Ryan & Deci, 2000). The perception of controlling rewards diminishes the sense of autonomy and hence decreases intrinsic motivation. Direct and positive informational rewards support the needs of competence and, in turn, boost intrinsic motivation. However, both intrinsic and extrinsic motivations are important constructs in promoting learning performance (Cerasoli, Nicklin, & Ford, 2014). Intrinsic motivation has also been associated with improved creativity and learning outcomes as well as psychological well-being (Ryan & Deci, 2000).

Incentive Systems, Motivation, and Learning

Achievement goal theory has identified two major types of motivational learning goals (Elliot, 2005). Performance goals reflect a desire to perform and demonstrate ability in comparison to others, while mastery goals reflect a desire to develop competence and achieve mastery oneself. Learners adopt different goals, which influence their behaviors, thoughts, and affects. Effects of incentive systems are heavily influenced by learners' goal orientations (Abramovich, Schunn, & Higashi, 2013). Different types of rewards can be invoked based on a learner's goal orientation to increase its impact on motivation and learning outcomes (Biles, Plass, & Homer, 2018).

The expectancy-value theory of motivation posits that learners' ability beliefs, expectancies for success, and subjective values are crucial factors for determining learners' performance, effort, and persistence (Wigfield & Eccles, 2000). Ability beliefs are defined as learners' perceptions of their competence to perform tasks. Expectancies for success are defined as probabilities of success on a task, and subjective values are defined as the values learners place on tasks. Reid, Paster, and Abramovich (2015) argue that learners' ability beliefs and expectancies for success can be task contingent or domain contingent, and subjective values can be related to identity or intrinsic value. Abramovich, Schunn, and Higashi (2013) contend that an incentive system has the potential to change learners' subjective values and expectancies for success.

Incentive Systems in Games

Wang and Sun (2011) identified eight forms of rewards in video games: feedback messages, unlocking mechanisms, developable avatars, item-granting systems, score systems, achievement systems, game resources, and plot animations. Points, leaderboards, and badges have been identified as the key elements in an incentive system (McKernan et al., 2015). Research on some of these forms of rewards exists, namely badges, points, levels, and leaderboards.

Badges According to Gibson, Ostashewski, Flintoff, Grant, and Knight (2015), "A digital badge is a representation of an accomplishment, interest or affiliation that is visual, available online, and contains metadata including links that help explain the context, meaning, process and result of an activity" (Gibson, Ostashewski, Flintoff, Grant, & Knight, 2015, p. 404). The function of badges should be to provide a sense of achievement to players (Wang & Sun, 2011). Badges should be issued to learners once they have met the requirements for earning the badges, and should contain metadata about the learner as well as the badge issuer (Reid et al., 2015). Badges can also be a hybrid of two assessment models, merit badges and gaming achievements, to recognize both formal and informal learning achievements. Biles and Plass (2016) implemented two types of badges in a geometry learning game and studied their impacts on learners with different goal orientations. Mastery badges were designed to reward the learner's own knowledge and skill by acknowledging personal progress. Performance badges, in contrast, were designed to reward the learner's performance in comparison to the other learners. Biles and Plass conducted a study with middle school students and found that badges that emphasized performance achievement led to better learning outcomes overall but that students with greater situational interest showed better learning outcomes with mastery badges. In a study by Filsecker and Hickey (2014) using a complex social inquiry educational game, middle school students gained a deeper understanding of scientific inquiry with the incorporation of badges as external rewards than did students who did not receive rewards.

Points, levels, and leaderboards Points, levels, and leaderboards are implemented to provide performance feedback and a sense of accomplishment to players (Przybylski et al., 2010; Wang & Sun, 2011). Points provide feedback to players for self-assessment (Wang & Sun, 2011), while levels and leaderboards can help players determine progress toward short-term and long-term goals (Nebel, Beege, Schneider, & Rey, 2016). A leaderboard is a visual display of players' rankings based on their accomplishment in the game, which players can use to compare their performance against those of other players (Christy & Fox, 2014). Leaderboards can also induce competition among players (Nebel, Schneider, Beege, & Rey, 2017). Competitive factors, and how leaderboards are embedded within gameplay mechanics, influence learner behavior and learning outcomes. Landers and Landers (2014) concluded that leaderboards can increase motivation to retry the game as well as increase time on task if leaderboard information is displayed at the end of the game. Willems et al. (2014) suggested that leaderboards should only be used when there are enough players to ensure fair and comparable competition among players. Nebel et al. (2016) observed an improvement in learning outcomes and a higher competitive effort when leaderboards were integrated into a game for college students for learning about allegorical paintings. They concluded that leaderboards in learning games enhance the focus on the learning tasks and hence improve knowledge retention among college students. On the other hand, in a game to train college-level learners about decision-making behavior, McKernan et al. (2015) found that learning was not affected by reward elements, including points and feedback. In addition, Deleeuw and Mayer (2011) found that adding a point system leading to prizes in an electrical circuit game had a positive effect for women but a negative effect for men.

Future Directions for Research on Incentive System Design

There is a paucity of studies focusing on the effects of incentive systems in games for learning, such as their impacts on learners' motivation and learning outcome. Future research should examine how incentive systems in different game types and genres impact learners' motivation and learning outcomes. We need a better understanding of the relationship between game genres, types of rewards, and their impacts on motivation, both intrinsic and extrinsic, as well as on learning. Another important area that requires further investigation is the relation between learning goals, interest level, rewards, and learning outcomes. More evidence is needed to understand how different types of rewards impact learning under different learning goals and interests. Lastly, a significant amount of research was conducted with university students. Future studies should consider including a more diverse population.

Identity Design

Many games have persistent virtual worlds populated by player avatars. In these worlds, each player is represented by a virtual agent that portrays their identity. Players experience these worlds through the lens of these agents. They take actions, develop skills, and interact with other players while embodying their avatars. As players spend more time in these worlds, they start developing a psychological connection with their avatars and start identifying with them (Turkay & Kinzer, 2014; Van Reijmersdal, Jansz, Peters, & Van Noort, 2013). This connection between the player and the avatar has been shown to increase gaming motivation and game enjoyment and evoke positive emotions (Ganesh, van Schie, de Lange, Thompson, & Wigboldus, 2011; Hefner, Klimmt, & Vorderer, 2007; Van Reijmersdal et al., 2013). Identity design is a practice that helps enhance this connection. It aims to recognize and develop game elements and features that promote identification with game avatars.

Summary of the Construct of Identity Design

Virtual identity has been a topic of interest in the media and games literature (Boellstorff, 2015; Turkle, 1994, 1996). Recently, many scholars have discussed the role of identity in games for learning (Barab & Duffy, 2000; Gee, 2003; Squire, 2006). In the book *What Video Games Have to Teach Us about Learning and Literacy*, Gee (2007) discusses three types of identities in games: real identity, virtual identity, and projected identity. Real identity comes from the player and is based on real-world values derived from the player's life experiences. Virtual identity is defined by the game character and the game narrative. This type of identity is ascribed to the character by the designers, and it is based on the background narrative and personality traits of the character. The projected identity is the interface between the real and virtual identities and allows players to craft the narrative of the avatar. Players generate this identity by projecting real-world values onto their virtual representations. This breakdown of types of identities has provided a framework for researchers to study identity in games as a reciprocal relation between players and avatars (Bessière, Seay, & Kiesler, 2007; Lim & Reeves, 2009; Turkay & Kinzer, 2014).

Theoretical claims regarding identification in games are supported by empirical findings (Bessière et al., 2007; Ganesh et al., 2011). Research has shown that players project their real-life values onto their avatars and perceive the avatars to be a close representation of their ideal selves (Bessière et al., 2007). In a study conducted by Bessière et al. (2007), players completed a personality survey from three different perspectives: their ideal selves, their real selves, and their virtual selves. Whereas the ideal self-perspective was about the person they want to be, the real self-perspective referred to players as themselves, and the virtual self-perspective referred to the personality of their avatar. Results of this study showed significant differences in ratings of these three personalities. The outcomes of the study also revealed that players rated their virtual identity to be a closer representation of their ideal selves than of their real selves. These findings provide support to the proposition that there are three types of gaming identities (Gee, 2003).

In addition to these findings, identity theory is also backed by neuroscientific evidence. In a study conducted by Ganesh et al. (2011), neural activity (as measured by fMRI) of *World of Warcraft* (Blizzard Entertainment, 2004) players was compared to a control group consisting of nongamers. During the study, participants in the treatment group were shown pictures of their gaming avatars along with images of humans and syllables, which were included as neutral stimuli. The control group was shown the same images, except that the avatar images were replaced by images of their favorite cartoon character. Results from the study showed that players had a significantly stronger emotional response to their avatar than to their favorite cartoon character. The results also showed that players' neurological response to their avatars was similar to their response to human beings, while this was not the case for nongamers' response to their favorite cartoon character (Ganesh et al., 2011). These findings suggest the existence of an emotional association between long-term gamers and their gaming identity.

Identity and Learning

The phenomenon of identification has an effect on in-game as well as out-of-game outcomes. Studies have shown that the sense of identity affects game enjoyment, gaming motivation, and learning outcomes (Hefner et al., 2007; Schmierbach, Limperos, & Woolley, 2012; Van Reijmersdal et al., 2013). In a study with *Battlefield 2* (Digital Illusions CE, 2005) players, Hefner et al. (2007) found that players' identification scores were strongly correlated with their game enjoyment. This effect is observed even when the player avatars are nonhumanoid. In a study conducted by Schmierbach et al. (2012), players were represented by customizable race cars. When investigating the effect of identity on game enjoyment, the researchers found that players who customized their cars had a higher sense of identity and in turn enjoyed the game significantly more than the noncustomizing control group. In addition to game enjoyment, players are also more motivated when there is a strong sense of identity. In a survey with 2,261 female players of the game *goSupermodel*, Van Reijmersdal et al. (2013) studied the relation between identity and gaming motivations. Results showed that players who associated strongly with their avatars also had higher gaming motivations. These studies shed light on the effects of identity on gaming outcomes. This increase in gaming motivation and enjoyment has an influence beyond gameplay and can, in turn, improve learning outcomes. Some researchers have conducted direct investigations to uncover this association (Cordova & Lepper, 1996; Ng & Lindgren, 2013).

The effects of game identification on learning have been discussed by many scholars (Barab & Duffy, 2000; Gee, 2003; Squire, 2006), but empirical evidence on the topic is scarce. A few studies, however, have provided preliminary evidence in support of the theoretical claims (Cordova & Lepper, 1996; Ng & Lindgren, 2013). Cordova & Lepper (1996) studied the effects of avatar selection and personalized narrative on learning outcomes in a math learning game. In this experiment, one of the groups was allowed to choose the visual appearance, as represented by game icons, of their own character and of the enemy character. Players in this condition were also allowed to name their character and pick a starting point on the game board. These choices were made randomly for the control group players. Results showed that players who were given choices had significantly better learning outcomes than those under the control condition. Similar results were found in an experiment conducted by Ng and Lindgren (2013). In this study, participants played a custom level of the game *Spore* (Maxis, 2008), a real-time simulation about evolution of organisms. After the gameplay session, researchers compared gameplay-related learning outcomes and found that students who were given the choice of customizing their characters had marginally higher scores than players who did not customize their characters. Although these results do not provide conclusive evidence, they are a substantial step toward uncovering the association between learning and identity in games.

Identity Design in Games for Learning

Early evidence of the positive effect of identification on learning outcomes promotes the use of different game elements for identity design. Studies have shown that game features such as avatar customization and game narrative have the potential to enhance player identification (Brookes, 2010; Turkay & Kinzer, 2014). A commonly studied game feature is customization of visual traits of avatars (Bessière et al., 2007; Lim & Reeves, 2009; Ng & Lindgren, 2013; Turkay & Kinzer, 2014). Allowing players to customize their avatar affects players' emotional arousal (Lim & Reeves, 2009) and sense of identity (Turkay & Kinzer, 2014). Researchers have studied the effect of allowing players to customize visual traits such as gender, skin color, hairstyle, facial structure, and body type. While most experiments have analyzed customization of many different traits together (Bessière et al., 2007; Ng & Lindgren, 2013), few have observed the effect of modifying a single trait. For example, Lim and Reeves (2009) studied the effect that choosing the avatar's gender had on the emotional arousal of players. Results showed that this choice had a significant effect on participants' emotional arousal response. The effect of customization on identity has also been studied longitudinally. Turkay and Kinzer (2014) conducted a study with *Lord of the Rings Online* (Turbine, 2007) players over two weeks, with a total gameplay time of 10 hours. The results indicated that the customization group identified significantly more with their avatars compared to the noncustomization group. Another interesting finding from the study was the effect of gameplay duration on the strength of identification. This effect showed that the bond of identification between players and their avatars grows stronger with time.

The game narrative is another feature that promotes identification with characters. In games where players embody a predesigned protagonist, the behavior and traits of the character moderate the degree of identification (Cohen, 2001; Flanagan, 1999). Some researchers have suggested that players identify with fictional characters based on character traits and personality. Brookes (2010) studied this effect by comparing two groups playing the same game but with different narrative dosages. The high-narrative group received a background narrative of the game character, while the low-narrative group wasn't given this narrative background. Results showed that the high-narrative group identified more with the game character at the end of a 30-minute gameplay session compared to the low-narrative group. These results are consistent with other studies showing the impact of narrative on identity and learning (Cordova & Lepper, 1996; Schmierbach et al., 2012). In addition to the background narrative, the emergent narrative of games also affects identity. As players spend more time in virtual worlds, they write their own stories through gameplay. While progressing in the game, players are also building a narrative that defines their game character. Although this phenomenon has not been studied directly, it is supported by evidence showing that player identification grows with time spent on gameplay (Bessière et al. 2007; Turkay & Kinzer, 2014; Van Reijmersdal, 2013). This evidence suggests that the bond between the player and the avatar evolves with time and can be associated with the evolving narrative of the avatar.

Future Directions for Research on Identity Design

The importance of identity in video games has been made clear by research (Bessière et al. 2007; Ganesh et al. 2011). Studies have found positive effects of identity on learning outcomes (Cordova & Lepper, 1996; Ng & Lindgren, 2013) and have highlighted the need for future work in the domain. However, scholars have raised concerns regarding the lack of experimental studies on the effects of identity design on learning outcomes (Turkay & Kinzer, 2014). To overcome this gap, more design manipulations and associated studies need to be conducted. So far, studies have only explored a fraction of the features available for identity design. Most research has focused on visual customization of avatars and game narrative but avoided other features, such as emergent narrative, social interactions, skill customization, and movement customization. Exploring the effects of these features may reveal additional ways of strengthening a sense of identity in players. The increasing popularity of new hardware, including virtual and augmented reality devices, has also provided new ways of increasing identification. These media have made presence and immersion design new factors in identity design.

Along with design innovation, there is also a need for new research designs. Factorial designs, as utilized by Cordova and Lepper (1996), can be a useful method for research on player identity. These designs help uncover the effect of individual factors as well as their interactions on identity design. Researchers also need to consider conducting long-term studies in authentic gaming environments. Previous research has established the connection between gameplay duration and identity (Bessière et al., 2007; Turkay & Kinzer, 2014; Van Reijmersdal, 2013) and has suggested the need to consider longitudinal designs in research. Finally, the effect of identity on learning needs to be studied using different learning outcomes and with different game genres. Research in this domain can further improve the effectiveness of learning games by utilizing the power of player identity.

Social Presence

The terms presence and immersion are often used interchangeably, which causes confusion (Bowman & McMahan, 2007). It is important to recognize the distinction between immersion and presence. Slater (2003) defines immersion as presentation of what technology can re-create in relation to the real world, which can be measured objectively. On the other hand, presence is defined as human perception or experience in an immersive environment, which typically is measured subjectively. Presence—the feeling of "being there"—has been studied by many different academic fields, including communication, psychology, computer science, and philosophy. Lombard and Ditton (1997) define presence as "the perceptual illusion of nonmediation." This illusion occurs when a person responds and interacts in a medium as if it doesn't exist, thereby making the experience feel real. Games have been described as a medium that possesses a unique quality to induce and promote presence (Kallinen, Salminen, Ravaja, Kedzior, & Sääksjärvi, 2007; Tamborini & Skalski, 2006). Different types of presence can be induced through games, such as spatial presence, social presence, and self-presence (Tamborini & Skalski, 2006). Spatial presence is determined by a game's ability to induce the feelings of involvement and immersion, while self-presence concerns how games cultivate a player's self-awareness (Tamborini & Skalski, 2006). Short, Williams, and Christie (1976) contend that social presence exists along a continuum and that its degree of salience is affected by individual perception and the capacity of the communication medium. In this section, we will explore the role of social presence in educational games and its impact on learning.

Summary of the Construct of Social Presence

Social presence can be simply defined as a "sense of being with another" and "being together with another" (Biocca, Harms, & Burgoon, 2003). This "another" can be a human being or a different form of intelligence, including a computer, robot, agent, and artificial intelligence. Social presence exists along a continuum rather than simply being present or not present (Biocca et al., 2003). Gunawardena (1995) described two concepts associated with social presence: intimacy and immediacy. Both intimacy and immediacy influence the level of social presence. Intimacy refers to a sense of connectedness in a relationship. Intimacy depends on physical distance, eye contact, and topics covered during communication (Argyle & Dean, 1965). Immediacy is a measure of psychological distance during interaction (Wiener & Mehrabian, 1968). Psychological distance can be measured in the form of nonverbal immediacy, such as physical orientation, facial expression, and attitude or verbal immediacy through speech and written communications. The medium plays an important role in social presence. The level of presence is subject to the player's interaction with and perception of the medium (Lombard & Ditton, 1997). Lombard and Ditton (1997) identified three concepts that are related to social presence and medium, namely presence as social richness, presence as a social actor within the medium, and presence as medium as social actor. Presence as social richness is related to the affordance and user's perception of the medium. Presence as a social actor within the medium describes how users interact with objects in the medium, such as virtual actors and characters. Lastly, presence as medium as social actor refers to social responses by users in responding to cues provided by the medium.

Social Presence and Online Learning

Studies have been conducted to examine the relation between social presence and performance. Most of the existing literature has focused on traditional classroom settings and online learning environments. Social presence has been associated with promoting different aspects of learning, including learning outcomes and learning satisfaction in an online learning environment (Kim, Kwon, & Cho, 2011; Liu, Gomez, & Yen, 2009). Social presence has been reported as a critical factor in determining a student's learning outcome (Kim, Kwon, & Cho, 2011). Picciano (2002) found that students in a high social presence group scored higher than students in a low social presence group on written assignments. Swan, Matthews, Bogle, Boles, and Day (2012) redesigned their online course with the community of inquiry (CoI) framework. The CoI framework includes three types of presences that support online learning: social presence, teaching presence, and cognitive presence. The revised version of the online course, based on the CoI framework, was linked to improved learning outcomes. Kearney, Plax, and

Wendt-Wasco (1985) reported that teacher nonverbal immediacy is critical for student affective learning outcomes in college-level classes. Christophel (1990) has also reported similar findings, showing that the use of immediacy improves student motivation and increases learning at the college level. In a study on using video in educational materials, Homer, Plass, and Blake (2008) found that media that present information in ways that enhance social presence can lead to increases in learner engagement and retention compared to media that do not enhance social presence.

Social Presence in Games

Biocca et al. (2003) identified three dimensions of social presence: copresence, psychological involvement, and behavioral engagement. Copresence refers to the sensory awareness of the other and the mutual awareness of the existence of the other. Psychological involvement refers to the sense of intelligence in the other, salience of the interpersonal relationship, sense of intimacy and immediacy, and mutual understanding. Behavioral engagement refers to behavioral interaction. Social presence triggers psychological effects on behavior. Tamborini and Skalski (2006) argued that these three dimensions of social presence can be experienced in games. They suggested that copresence can be achieved in most of the games with nonplayable characters sharing the game world. Copresence can be further enhanced by mutual awareness among players and agents. Psychological involvement can be experienced when players perceive that intelligence is present in agents. Artificial intelligence in nonplayable characters creates cues required for players to believe they are interacting with social beings and can increase their psychological involvement. Von der Pütten et al. (2012) found that perceived interactivity of a virtual character and social presence was positively correlated in an augmented reality game. Heeter (1992) suggests that increases in avatar communications and interactions lead to increases in social presence. Behavioral engagement can be introduced through talking, chatting, and identifying nonverbal cues from other players or agents. Dialogues and eye contact between players and agents, and voice or text chatting among players, are some of the examples.

Studies have concluded that players experience higher levels of social presence when they are playing against human-controlled opponents (Heeter, 1992; Weibel, Wissmath, Habegger, Steiner, & Groner, 2008). Xu et al. (2008) found that a mobile augmented reality board game with shared space increased social presence among players compared to playing with a shared board or separate board. Lee, Jeong, Park, and Ryu (2011) found that networked interactivity features (i.e., real-time online connections among players) in an educational quiz game have positive effects on social presence as well as test performance. Takatalo, Häkkinen, Kaistinen, and Nyman (2010) identified game components and player behaviors that influence the level of social presence. Narrative and the player's role engagement are crucial factors. Takatalo et al. also pointed out that it's important to establish similarity between the game world and real-world objects as well as people. Guadagno, Blascovich, Bailenson, and McCall (2007) reported that players experience high social presence when agents are high in behavioral realism. Nowak and Biocca (2003) suggested that the use of less anthropomorphic images in virtual human representation increases the perceived level of social presence compared to no images or highly anthropomorphic images. A plausible explanation is that highly anthropomorphic images set up high expectations. However, a failure to meet these expectations reduces the level of social presence. Lastly, a strong correlation between social presence and player satisfaction in virtual worlds (e.g., virtual reality and augmented reality) has been reported (Bulu, 2012; Jung, tom Dieck, Lee, and Chung, 2016).

Future Directions for Research on Social Presence

There are a lot of studies looking into social presence in games. However, studies examining social presence in educational games and its effect on learning are scarce. Most of the existing studies investigating presence and learning are focusing on college-level learners in an online learning environment. Future research should further investigate how different game design elements impact levels of presence perceived by learners. It's also important to examine the effects of presence on learning performance. More diversity in types of games should be investigated, as different game types might induce different types and levels of presence in learners. More diversity in culture, ethnic background, and age groups of participants is also needed. Lastly, studies should consider confounding factors such as learners' game-playing experience and skills.

Conclusion

The empirical research available for the design factors described in the model of game-based learning (Plass et al., chapter 1 in this volume; Plass et al., 2015) varies greatly. While sufficient research is available for some of these factors, for others only a small body of literature exists that reports on empirical research on the effect of these factors on learning outcomes for games for learning and that could guide designers. In this chapter, we therefore focused on three of these design factors: incentive systems, identity design, and social presence. Incentive systems, which consist of a number of design features that provide rewards to players, are often used to motivate and guide player behavior. Even though only limited research exists in the context of games for learning, the existing research from entertainment games, as well as their use for gamification, makes it likely that incentives can have similar effects in learning games. However, future research is needed to provide designers with guidance, especially on the benefit of extrinsic versus intrinsic rewards and their relation to learning variables such as goal orientation.

Identity design is a practice that supports the development of a psychological connection between the players and their avatars in order to support learning. Even though some research has found a connection between identity design and players' motivation, facilitated especially by giving players choices in customizing visual traits of their avatars and by using a narrative, the connection to learning outcomes requires increased empirical evidence.

Social presence is the sense of having other players in the game. While research in traditional classroom settings and online learning has established a connection between social presence and motivation as well as learning outcomes, only limited empirical research makes the same connection in the context of games for learning.

Overall, these three design factors are worth investigating, as they show promise in being able to enhance motivation and outcomes in games for learning. We included recommendations for future research at the end of each section that would provide evidence for designers of learning games and that establishes a stronger link between these design factors and learning outcomes.

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IV Applications of Game-Based Learning

16 Game-Based Learning in Science, Technology, Engineering, and Mathematics

Eric Klopfer and Meredith Thompson

Introduction

The topics of science, technology, engineering, and mathematics (STEM) are a popular context for learning games and serious games because of the alignment of themes such as underlying systems and computation (Boyle et al., 2016). Among the suite of pedagogical strategies available to STEM educators, serious games are uniquely well suited to motivate learning, present complex material incrementally, and engage learners in "doing STEM" activities. Learning theory, science and mathematical topics, and the history of educational technology help form links between STEM education and games. Our goal is to illustrate how the attributes of serious games can be leveraged as powerful learning tools for science, technology, engineering, and mathematics education through situated learning. Before we examine these attributes in depth, we will first define what we mean by STEM and why this is an important domain, as these issues tie directly to the connection with games.

STEM refers to the disciplines of science, technology, engineering, and mathematics. In context, the term STEM is often used to make arguments about workforce development and the type of education that will best prepare individuals for STEM careers. School is the primary way most students learn about STEM fields and an opportunity to challenge stereotypes and build children's confidence in their ability to do STEM activities and to be included in STEM careers. Optimal STEM education is real-world, relevant, and related to the learner. Real-world STEM is situated in authentic and engaging contexts, such as problem-based and inquiry-based learning; relevant, including a clear link to STEM activities that help people and communities in addition to developing new technologies and processes; and relational, so that individuals can envision themselves as having the ability and the agency to do STEM. A broader yet equally important goal for STEM education is to prepare all US citizens to be literate in science, technology, engineering, and mathematics so they can participate effectively as decision makers in a democratic society (AAAS, 1994). Engaging students in STEM fields and building their self-efficacy and confidence in being able to do science, mathematics, and engineering are essential to meeting the dual goals of developing talent for STEM careers and developing STEM literacy among the population.

Educational games are intended to help students learn STEM concepts, practice skills, and refine their problem solving and computational thinking skills by providing scaffolded authentic context and inquiry-driven investigations. Thoughtfully designed games engage learners in the game (Boyle, Connolly, Hainey, & Boyle, 2012), provide ongoing feedback, and adapt to the player's ability (Gee, 2007). STEM games give players a specific purpose and rationale to collect data, solve problems, find patterns, and design solutions, thereby developing and refining skills that are valuable practices in STEM fields (Morris, Croker, Zimmerman, Gill, & Romig, 2013). Since students are given a context and purpose for their knowledge, they are less likely to ask, "Why are we supposed to know this?"

Defining the Scope of This Chapter

There are many variations on what might be considered science, technology, engineering, and mathematics (STEM) games. For the purposes of this chapter, we consider STEM games as those in which the game design and content are intricately linked, the actions of the player are STEM related, and the primary goal of the game is to help students learn about concepts and develop skills that are related to STEM domains. According to Clark, Tanner-Smith, and Killingsworth's (2014) meta-analysis of games, "Design, rather than medium alone, predicts learning outcomes" (Clark, Tanner-Smith, & Killingsworth, 2014, p. 14). Thus, we will examine games that are designed to target STEM learning and STEM topics.

Before investigating some of the aspects of gaming that uniquely and deeply connect STEM learning and gameplay, it is useful to distinguish two categories that we will not consider—gamification and citizen science games. In exploring the domain of STEM games, many common examples may be considered gamification, applying some set of game mechanics to otherwise unrelated tasks. A canonical example in this category would be one of the most popular educational games of all time, *Math Blaster*. In *Math Blaster*, players need to shoot items out of the sky by matching the answer to the problem. For example, the math problem might be "6+2," and the player would then need to shoot the number "8" out of the sky. While this is a game that can develop skills in a STEM domain, it will fall outside our scope of what we call STEM games. The questions and answers in this case could just as easily be vocabulary words and definitions. Game-based learning is more than adding points and gold coins to a typical set of math problems; game designers employ narrative and conflict to engage and motivate students to learn and practice math (Plass, Homer, & Kinzer, 2015). Games in which the content is easily substitutable and the player's actions are not directly related to the STEM learning fall outside the scope of this chapter, even when there is evidence that motivation or learning gains can be measured through gamification.

Some STEM-related games engage participants in science practices but are only designed for participation in a study and not edification about the topic. There is also the growing genre of citizen science activities, which use game mechanics to crowd-source data collection and analysis for science research. The most well-known example here is *Foldit*. *Foldit* challenges players to fold computer models of proteins following the scientific rules of the real world. The game scaffolds and motivates players to succeed in these complex tasks, which in turn generate real data that help solve scientific problems. One paper resulting from this effort included thousands of players as authors (Cooper et al., 2010). While some players may learn about the science of proteins, and educational programs have been devised as secondary outcomes, for the most part, players are really just doing computation. This genre can be quite successful in crowdsourcing efforts, and many other games have followed this same model. Given that these games are not primarily focused on learning as an outcome, we do not consider them here.

What this chapter does explore is the deep connection between STEM learning and games. We start by examining learning objectives for STEM education and then describe how games can address the systems, scale, and practices that are interwoven in STEM fields. We consider the cognitive, affective, and sociocultural affordances of game-based learning, especially as they relate to STEM domains. Finally, we propose some future research directions for STEM game-based learning.

What Is Game-Based Learning in Science, Mathematics, Engineering, and Technology?

Research suggests that effective STEM learning environments include cognitively demanding tasks, focus on complex problem solving, and encourage collaboration and the use of technology (NRC, 2011). K–12 teachers have to ignite student interest in STEM, create learning opportunities that develop students' knowledge and skills, and foster their students' belief that they can engage in STEM domains in school and as a potential career. Increasingly, national standards call for students not only to learn content but also to participate in the practices of STEM fields and understand how STEM fields are situated within the larger context of society. While this is a valuable goal, the limited time and resources make classrooms a challenging environment for authentic science, engineering, and mathematical practice. Educational games can fulfill this need by engaging students in the conceptual ideas of STEM fields and providing a space where students enact the content, skills, and practices embodied in the standards (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; NGSS Lead States, 2013), so that students can learn and practice skills, develop a positive attitude about STEM, and consider STEM career options.

Content

Science concepts are the focus of many serious games, and interest in using games in teaching science continues to expand (Cheng, Chen, Chu, & Chen, 2015). Many STEM-focused games are designed with the hypothesis that gameplay will help students learn and review concepts in science and mathematics (chapter 5 in this volume). Game environments allow students to explore locations that may otherwise be unreachable, such as outer space, the edge of a volcano, or the inside of a cell. The affordances of games enable students to grapple with phenomena that may otherwise be invisible, such as using virtual reality games to understand relative motion in physics (Kozhevnikov, Gurlitt, & Kozhevnikov, 2013) or to allow students to explore three-dimensional objects in mathematics (Kebritchi, Hirumi, & Bai, 2010). While simulations and modeling platforms allow students to examine forces and phenomena, those platforms do not include a narrative theme, personal perspective, or the level of goal-directed feedback that is regularly incorporated into a game. Therefore, simulations and modeling fall outside the scope of this chapter.

Skills

Through games, students are able to learn and practice basic skills and foundational knowledge that will become useful in other contexts, an idea called "preparation for future learning" (Reese, 2007; also chapter 1 in this volume). For example, games such as *Lure of the Labyrinth* introduce middle school students to concepts such as finding unknown quantities and exploring ratios and proportions while doling out food in the monster cafeteria (Reid, Jennings, & Osterweil, 2013). These examples highlight innovative and forward-thinking uses of games and simulations. Unfortunately, there are many examples of gamified "drill and practice" or "vocabulary review" activities that are also categorized as games and are commonly used in classrooms (Rocha, Tangney, & Dondio, 2016).

Practices

Games have great potential to engage directly in practices of science, technology, engineering, and mathematics. The inquiry-based and problem-solving activities of asking questions, planning investigations, and constructing explanations mirror the "probe, hypothesize, reprobe, rethink" process players conduct during play (Gee, 2007). STEM games are useful in demonstrating crosscutting concepts of cause and effect, demonstrating models of systems, exploring scale and proportion, and understanding the concepts of stability and change. Students are able to relate core ideas of a discipline, such as matter and its interactions, energy and motion, and stability, to their everyday lives. Game narratives provide contexts for introducing basic concepts and gradually developing understanding of complex topics (NGSS Lead States, 2013). Similarly, games can be useful tools in enacting the Common Core Standards for mathematical practice, such as understanding problems and persistence in problem solving, making models, and reasoning abstractly (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010).

Examples of Game-Based Learning in Science, Mathematics, Engineering, and Technology

We see three primary ways that STEM games draw on mechanics that deeply connect the activity and learning objectives. In particular, games allow educators to communicate important ideas about systems, scale, and practices. While these may not be entirely unique to STEM, they are a predominant theme.

- *Systems*: STEM games are often based on systems. These can be simulations of real-world systems, as in many sciences, or any kind of underlying model that governs interactions based on a coherent set of rules, as we might see in mathematics.
- *Scale*: Understanding scale is essential to understanding STEM concepts, and STEM games often rely on the use of different scales. This may be to help learners understand very large or small spatial scales or similarly manipulate temporal scales.
- *Roles*: STEM games are often tied to STEM disciplinary practices. That is, what players do in games models the practices of professionals in the discipline. This varies from methods for approaching problems to analyzing data about those problems and sharing findings with others in the community.

Here we provide an overview of how STEM games employ these tools by building on some examples of games that have used them.

Systems

Simulations are helpful in describing and understanding STEM concepts, especially complex and interrelated systems. Starting in the 1990s, the advances in and availability of technology in the classroom enabled many teachers to incorporate computer-based simulations in their classrooms (Feurzeig & Roberts, 2012). This interest in simulations catalyzed platforms for using and creating simulations such as the tools for modeling system dynamics in *Model-It* (Soloway et al., 1996) and *StarLogo* (Resnick, 1997). Today we see significant use of simulations in classrooms from libraries like *PheT* (Wieman, Adams, & Perkins, 2008) and *WebMO* (Schmidt & Polik, 2017). A recent meta-analysis (D'Angelo et al., 2014) investigated learning outcomes associated with STEM simulations and found significant gains in learning across a variety of domains. The researchers also found that simulations that were supplemented with additional scaffolding led to additional learning. This outcome had been supported by previous research (Linn, Chang, Chiu, Zhang, & McElhaney, 2010), where it was noted that simulations are more effective when (among other things) they are scaffolded and personally relevant. While there is great enthusiasm for simulations and educational games in STEM, the evidence linking games and simulations to STEM learning is still limited (Honey & Hilton, 2010).

Games can augment simulations by providing additional scaffolding and context to make the simulation more relevant and the exploration more structured. Embedding simulations within a larger context of inquiry also enables students to include STEM capabilities in their own identity (Beier, Miller, & Wang, 2012; Gilliam et al., 2017). The structure that games provide can also include narrative to guide students, goals to help structure investigations, and feedback that serves as formative assessment.

Examples in this category span many domains. One recent example in the physical sciences is *Surge* (Clark et al., 2011) (figure 16.1), which has gone through a number of design iterations. The basic premise in *Surge* is that the player needs to navigate a spaceship through a complex set of obstacles. The game employs models of mechanics based on Newton's laws, and the player navigates by manipulating forces and speeds. In the life sciences, the *UbiqBio* series of games (Perry & Klopfer, 2014) modeled a series of biological systems ranging from DNA to genetics and evolution. In the genetics game *Beetle Breeders*, students need to breed exotic beetles with particular characteristics, based on models of Mendelian genetics. The same kinds of systems principles can be applied in mathematics as well. The *Dragon Box* (figure 16.2) series of games has employed this principle by building models of mathematical systems. In *Dragon Box Algebra*, algebraic systems are modeled as interactive systems where students need to balance equations by manipulating two sides of a system (Liu, 2012).

Figure 16.1
Surge (Clark et al., 2011).

Figure 16.2
Dragon Box (Siew, Geofrey, & Lee, 2016).

In each of these games, players interact with an underlying system or mode; however, a series of tasks or levels that scaffold the process for students are also included. Similarly, each of the games is centered around some context, story, or narrative that contextualizes the actions of the player. Sometimes this is a very weak narrative, but it does provide some of the relevance that makes the actions in the game more understandable. *Dragon Box* has been linked to improved reasoning, problem solving, and student attitudes toward algebra (Siew, Geofrey, & Lee, 2016).

Scale

Games provide a means for experiencing phenomena at different scales. Students face many conceptual difficulties trying to understand concepts at spatial and temporal scales that differ from their common experience (Grotzer et al., 2015). Novices struggle with fundamental concepts such as protein folding, interplanetary interactions, and evolution in part because of a lack of firsthand experiences at those scales. In STEM games, players can become part of a system and gain experience at those scales. For example, the game *Virulent* (Corredor, Gaydos, & Squire, 2014) (figure 16.3) places players at the scale of a virus trying to inject itself into a host cell. The player must think like the virus and take that perspective in order to be successful at overcoming the cell's defenses. Students who played *Virulent* developed more sophisticated mental

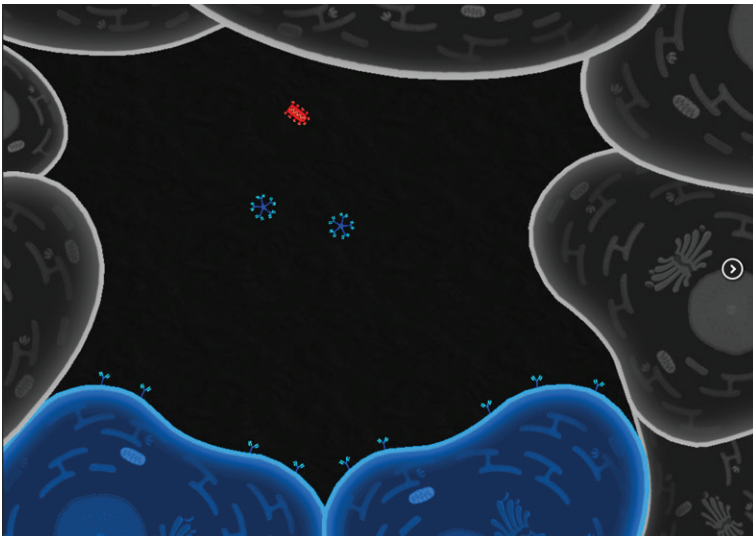

Figure 16.3
Virulent (Corredor, Gaydos, & Squire, 2014).

models of changes over time in systems than students who used text and diagrams (Corredor, Gaydos, & Squire, 2014).

The same kinds of challenges that are faced on small spatial scales are present at large ones. The game *Planet Mechanic* (Filament Games, 2016), shown in figure 16.4, challenges players to design planets and solar systems to fulfill different criteria and understand the relationship between moons and planets. This large scale is also a challenge for understanding phenomena that take place over long periods. The massively multiplayer game *Radix Endeavor* (Clarke-Midura, Rosenheck, & Groff, 2015) puts players in the role of scientists trying to apply science to solve real-world problems. Playing *Radix Endeavor* fostered students' skills in problem solving in genetics as well as other domains of science included in the game (Cheng, Rosenheck, Lin, & Klopfer, 2017). One of the domains that it explores is evolution. Players need to understand how traits might have changed and might change in the future as a result of different selective pressures. In one of the evolutionary quest lines, players explore differences in bird traits across regions. They utilize in-game tools to collect data on a micro level about individual birds' beaks and identify patterns. Then they use the evo globe tool (figure 16.5) to run simulations on a macro level. For example, they can adjust certain environmental factors related to available food sources to see how beaks in each bird population might evolve over time. Based on this evidence, along with other discoveries about the birds' environments, players are able to develop their own explanations

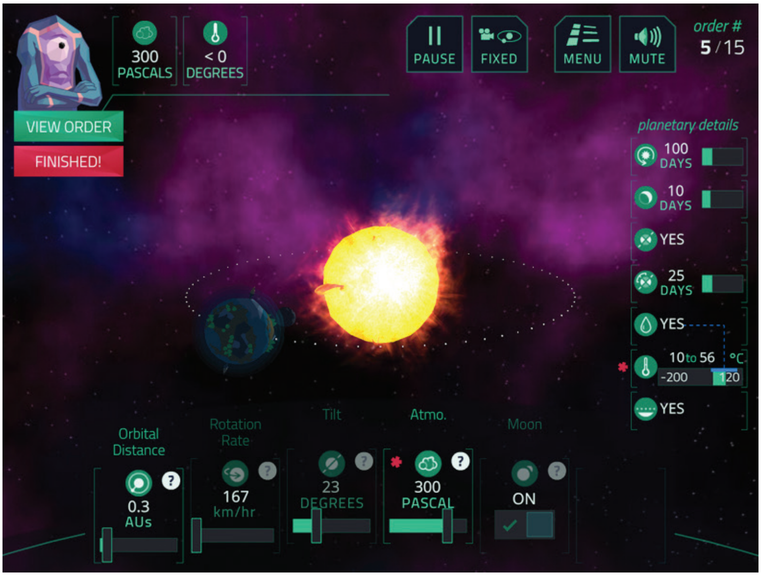

Figure 16.4
Planet Mechanic (Filament Games, 2016).

Change the settings to model the environmental conditions in the forest until the teebeedee birds' traits match the current forest birds. Figure out what caused there to be so many strong-beaked birds.

Figure 16.5
The evo globe in *Radix Endeavor* (Clarke-Midura, Rosenheck, & Groff, 2015).

for the differences in traits within each population. This particular example raises interesting challenges. We want to give players the capabilities to control what is going on in a game, yet we don't want to introduce or reinforce misconceptions about agency in evolution. Creating unrealistic agency in systems was a criticism of the popular game *Spore* (Bohannon, 2008). STEM games should be designed to give players agency and decision-making capabilities in a way that reinforces accurate ideas about the STEM domains rather than creating or reinforcing misconceptions.

Roles

Games are often designed to place players in particular roles. That happens explicitly in the genre of role-playing games (RPGs), where different kinds of characters possess different skills that must be employed in particular combinations. For example, in a typical RPG, some players might be able to block damage and others might create damage, and they would need to work together to combat a powerful foe. The key here is that being effective in your role requires understanding and applying that particular role's capabilities, and that in turn must fit with the way that other characters are operating.

This idea can apply directly in STEM games as well. The previously mentioned *Radix Endeavor* was built on this principle. Players played the roles of scientists in a Renaissance-like era of scientific understanding and played the roles of biologists and mathematicians in acquiring and applying that knowledge. *Quest Atlantis* and *Quest Atlantis Remixed* (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005) created 3-D virtual worlds in which players both learned science practices and thought about how they could apply that learning outside the game world (as shown in figure 16.6). For example, in the Taiga unit, players needed to figure out why fish were dying off in the world by using scientific measurements, data, and scientific reasoning. That role-playing need not take place entirely on-screen. In *Environmental Detectives* (Klopfer & Squire, 2008), students used mobile handheld devices to engage in an augmented reality role-playing game where they needed to solve an impending environmental crisis. The game was situated in a real location, based on a realistic but fictionalized scenario, and utilized many of the features of the actual locations. Students played various roles in which they could collect (virtual) water or air quality data, perform analyses, or implement remediation, triggered by locations or events in the actual world.

In each of these cases, the role is imposed on the player or they can choose among roles. However, environments can be constructed in which players create and tailor their own identities around a chosen set of practices. In the alternate-reality game *Vanished* (Anderson, 2011), players are presented with a scenario in which they are contacted by a race of beings from the future who have discovered an Earth-like planet devoid of life and need help figuring out what went wrong. Players are not assigned roles, but there is a diverse array of activities to engage in, including collecting backyard measurements, playing online games, visiting real locations, conversing with

Figure 16.6
Quest Atlantis Remixed (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005).

scientists, and participating in forums to debate theories. Each player engaged in some subset of these activities, specializing in data collection, theory analysis, or measurement. Each of these was associated with a set of practices that they embodied, which was further reinforced by discussions with practicing scientists. Interviews with participating educators and analysis of the forums revealed many instances of students engaging deeply in scientific discourse and even transferring knowledge outside the game as groups formed in the game collaborated in additional problem-solving activities (Klopfer, Haas, Rosenheck, & Osterweil, 2018).

Custom versus Curated Content

The examples just discussed describe games that have been explicitly designed for learning, much of that in schools. There has been a lot of interest and a number of resources dedicated to this kind of game. Looking at the genre of games used for STEM learning, there are two additional categories of games worth examining. In addition to games created explicitly for STEM learning, there is also extensive use of commercial off-the-shelf (COTS) games that teachers have used for STEM learning, and also modified versions of COTS games that have been redesigned to focus specifically on STEM learning.

For many years, teachers have used games for teaching math and science. Games such as *SimCity*, *Zoo Tycoon*, *Roller Coaster Tycoon*, and many others in the "sim" genre have been repurposed by teachers for use in the classroom. More recently, physics-based games such as *Angry Birds* (Sun, Ye, & Wang, 2015) and mathematics-based games such as *Minecraft* (Bos et al., 2014) have been adapted for use in the classroom. The underlying simulations within these games make them particularly suitable for such repurposing. These games also generate a significant amount of quantitative data and graphical representations that can form the basis of analyses. Teachers often cite the use of student-generated data as a means of making students more invested in these studies. While many of the benefits of such usage remain anecdotal, researchers have studied games outside the sim genre. Steinkuehler and Duncan (2008) studied the use of the massively multiplayer online role-playing game *World of Warcraft* and the scientific practices in which its players engaged. Their study found players regularly engaging in a suite of related scientific practices, including modeling and argumentation, not only in the game but on the discussion boards that players frequented outside the game.

This history of repurposing STEM games has inspired others to modify some of these games. One well-known example is *SimCity EDU*, a version of *SimCity* that was licensed by the game company Electronic Arts. This version, developed by GlassLab, emphasized systems thinking and provided a curriculum around the game as well. Similarly, Shute utilized *Newton's Playground*, which was a modified version of *Crayon Physics* (Shute, Ventura, & Kim, 2013), as well as a modified version of *Plants vs. Zombies* (Shute, Moore, & Wang, 2015), to study science-related practices through stealth assessment.

Games as Educational Interactives

Television shows such as *Sesame Street* have had an enormous impact, preparing generations of children to read and write even before they reached the classroom (Sherry, 2015). As games and interactive media have become a more ubiquitous experience for young children, educational games have been connected with broadcast media to play a role in building skills and reinforcing positive attitudes toward STEM. For example, the mathematics-based show *Cyberchase* incorporated STEM-based themes into the vocabulary, narratives, and interactive games, encouraging children to engage in STEM-based thinking and problem solving. The companion website for *Cyberchase* includes interactive games that allowed viewers to explore the themes in the show in more depth. Through these games, children were determining how much water will fill an unusually shaped container in *Pour it*, estimating numbers quickly in *Estimation Contraption*, or creating geometrical patterns in *Tessellation*. These types of experiences have helped children learn mathematics concepts and develop positive attitudes toward mathematics (Ferdig, 2013; Fisch, 2003).

Implications for Cognitive, Motivational, Affective, and Sociocultural Theory

Thus far, we have explored how educational games enable learners to explore three domains (systems, scale, and practices) in STEM disciplines. Next, we focus on the implications of educational games in light of theories in cognitive, affective, and sociocultural domains, zeroing in on the implications of those theories for STEM learning and teaching.

Games have the potential to catalyze a number of learning outcomes among students, including content and procedural knowledge, collaboration, design, affective and motivational influences, and social interaction, although much of the research still uses individual learning by students as the primary outcome (Cheng et al., 2015; chapter 5 in this volume). Not surprisingly, researchers draw on many different theoretical frameworks to describe how individual learning happens in games (e.g., behaviorism and constructivism). Viewed together, these theoretical frameworks appear disjointed and at times contradictory. We argue that games engender situated learning by placing the learner in environments where they can construct new knowledge, motivating students to learn and practice skills, and introducing students to a community of practice within the game and with other students (Lave & Wenger, 1990; chapter 7 in this volume). Situated learning theory is our overarching theoretical framework for how students benefit from game-based education.

Integrating the learner into a community of practice around a specific idea or concept can facilitate situated learning. A carefully constructed game environment can be a proxy for a community of practice, giving learners context, guidelines defining quality work, and a group of other players or characters to interact with while playing the game. In addition to providing a context for learning skills and knowledge, the game itself can serve the role of a master teacher (Squire & Klopfer, 2007). Players learn about the tacit assumptions that scientists make when studying evolution or how engineers design earthquake-proof buildings, simulating a cognitive apprenticeship (Brown, Collins, & Duguid, 1989). Ideas about learning, such as matching the task to the learner's current capabilities as a master teacher would do, are present both in situated learning theory's idea of apprenticeship and sociocognitive constructs such as working within a "zone of proximal development" (Cheng et al., 2015; Vygotsky, 1987) or a "regime of competence" for the learner (Gee, 2007). Games initially provide a great deal of support for the beginner (scaffolding), which fades over time as the player demonstrates knowledge.

Similar to an apprenticeship, games begin with simple representations of an activity, allow practice at that level, and gradually introduce additional complexity and reduce supports as the learner demonstrates competence. Simulation-based games help learners gain understanding of topics such as scientific experimentation by representing abstract concepts in helpful ways and allow students to "mess around" with virtual materials, develop skills effectively, and allow failure without the cost of extra materials (Thompson et al., 2016; Triona & Klahr, 2003).

Children are naturally curious and are capable of complex problem solving. However, mathematics and science involve simultaneously learning a new language and an approach to viewing and explaining the world that may seem counterintuitive

(Gee, 2007). For example, introductory physics often asks learners to assume a world without friction. While this may simplify mathematical calculations, it contradicts students' own experience. Sun, Ye, and Wang (2015) found that game-based teaching methods using commercial games allowed students to explore physical concepts, such as pendulums through *Cut the Rope* and circular motion through *Angry Bird Space*. These games gave context to the physics problems, allowing students to explore and assimilate new ideas into their knowledge base. Other aspects of the structure of games can also facilitate learning; in particular, these games also helped scaffold learning situations by leveling or gradually increasing the complexity of the simulation so it better represents student experience (Sun, Ye, & Wang, 2015).

Games may represent a preliminary step into learning that may not directly translate to measurable explicit learning but becomes a foundation for additional instruction to accelerate and enhance learning. Much of this work builds on the principles of preparation for future learning (Bransford & Schwartz, 1999; chapter 1 in this volume). One good example that tests this theory is a study by Arena and Schwartz (2014) on *Stats Invaders*, a modified version of *Space Invaders*, used to teach statistics principles. Their study found that while playing the game may not lead to explicit learning, the game combined with additional learning experiences produced significant learning gains.

Learning is a complex process that has been studied from many angles. Constructs from cognitive science and psychology can be useful lenses for understanding and investigating how learning results from different facets of game design and implementation. Game design reveals the designers' epistemological beliefs and ideas about how people learn. Plass et al. (2015) observe that learning theory is woven into the architecture of the game: a game with few choices and very little feedback suggests a behaviorist view of learning, while a game in which players have the agency to choose challenges, create virtual artifacts, and work collaboratively suggests a constructivist view of learning.

Cognitivist ideas about learning describe the processes and capacities of an individual, both of which are useful in designing and studying educational games. Cognitive load theory suggests that optimal instructional design is informed by an understanding of the capacity of the brain to process information (Sweller, 1988; Van Merrienboer & Sweller, 2005). Cognitive scientists recognize and have devised research-based recommendations for designers of multimedia learning environments to reduce cognitive load by segmenting information into smaller pieces, eliminating redundancy, and synchronizing visual and auditory information (Mayer & Moreno, 2003, chapter 5 in this volume). Cognitive theories of learning will continue to inform game design and research as educators are looking to apply laboratory-based cognitive science findings to complex educational settings (Brown, Roediger, & McDaniel, 2014, chapter 4 in this volume).

Some features of game-based learning are particularly well aligned with current recommendations of cognitive scientists: interleaving of different kinds of problems, spaced iterative learning episodes, and providing ongoing feedback about the experience (Deans for Impact, 2016). Traditionally, students learning new concepts have been given practice problems grouped, or blocked, according to the type of problem-solving strategy. Cognitive scientists have found that interleaving different types of problems early in the learning process promotes deeper understanding (Rohrer, Dedric, & Stershic, 2015). Spacing learning episodes over time, rather than condensing learning into shorter time frames, is also beneficial for learning and retention of information (Brown et al., 2014). Games, by design, meet both of these recommendations: they are intended to be played again over time and allow players to practice similar skills repeatedly but in an open-ended way, so the player has to select and try different strategies. The same strategy may work well in one instance of the game but not in a different one (Gee, 2007). Players are able to monitor their own progress because feedback is one way to motivate players to continue playing, and thus it is integrated into game design. In educational contexts, ongoing feedback allows learners to take ownership of their own learning and progress and become self-regulated learners. Feedback is extremely helpful for teachers; monitoring student progress allows them to plan instruction effectively and address problems and issues. Game-based assessment holds great promise in giving teachers and students a mechanism for revealing student understanding (Clarke-Midura et al., 2015; Shute et al., 2013).

Engagement and motivation are often cited as affordances of educational games, as discussed by Ryan and Rigby (chapter 6 in this volume). Games can help students engage with science curricula such as genetics (e.g., Annetta et al., 2009) and math (Divjak & Tomić, 2011; Ke, 2008) and spark interest in STEM careers. Games can help build students' self-efficacy in STEM through well-crafted experiences that provide early success and that slowly increase the difficulty of the task (Chen & Usher, 2013). In addition to building self-efficacy, games allow students to join a virtual community of practice, building their identities as possible scientists (or mathematicians) and their interest in science careers (Squire & Klopfer, 2007). Fostering self-efficacy in STEM skills and practices and identification with STEM careers helps learners gain a better understanding of STEM ideas and encourages them to consider pathways into STEM careers.

Limitations of Current Research and Implications for Future Research

Well-designed games are engaging and motivate players to continue playing (Boyle et al., 2012; Zimmerman, 2011). Educational games aim to leverage the motivation and engagement of entertainment in order to foster learning. The two goals of knowledge acquisition and engagement are the main educational outcomes researchers attribute to games. However, existing studies provide varying support for the link between these outcomes and game-based learning. In two recent meta-analyses, Girard, Ecalle, and Magnan (2013) concluded that evidence for learning was present but there was no evidence for increased motivation, while Boyle et al. (2012) concluded that evidence for motivation was strong but evidence for learning was weak. This divergence may result from the different goals, learning outcomes, and implementation strategies used in educational games (Wouters et al., 2013). In order to facilitate comparison across studies of educational games going forward, studies should describe and discuss not only the design of the game itself but also the materials and experiences provided to the learners and the teachers to enable inclusion of games as a learning experience in the classroom.

A focal point for the future of game-based education is to understand how game design relates to theoretical ideas and to intended learning, motivational, affective, and sociocultural outcomes. Establishing a common vocabulary for describing games would enable researchers to specify their own designs and understand others' approaches with additional clarity. A clear and comprehensive description of game implementation is also useful for understanding outcomes. How is the game introduced to the learners? How do players reflect on what they have learned through the experience? As games are often proxies for authentic experiences and practical outcomes, it is critically important to study how much learners are able to transfer what they learn from games into their own lives. Currently, few studies of educational games establish clear links between learning in the game and transfer to more realistic situations (Girard, Ecalle, & Magnan, 2013). Additionally, it will be useful to draw links between aspects of the design of the games and accompanying implementation strategies and outcomes related to learning, motivational, affective, and sociocultural concepts. For example, how is transfer related to abstract representations in games? What types of game designs are best for motivational learning outcomes versus specific conceptual ideas? How do games help learners comprehend complex systems and models that are prevalent in STEM education? What roles do accompanying material and teacher presentation play in the successful use of games in classrooms? Does identity formation resulting from games persist over time and influence future course selection?

While the field of educational games benefits from a wide variety of approaches, examples, and applications of games, this variety can be challenging to organize and systematize into a cohesive body of work that is accessible to education researchers and game designers. Cognitivist, constructivist, situated, and other theories of learning help situate game design and educational outcomes within the larger field of educational research. Thus far, research studies often do not specify learning theories (Cheng et al., 2015), and those that do often apply them only during game design, without considering the implementation of the game (Li & Tsai, 2013). Integrating learning theories throughout the design, implementation, and research activities of educational games will allow findings from individual studies to inform the broader field of educational game design and implementation.

Implications for the Design of Game-Based Learning

Well-designed STEM games provide learning affordances that help students learn about crosscutting concepts in STEM such as systems and scale, engage in STEM practices (Bressler & Bodzin, 2013), and be motivated to learn STEM and consider STEM careers (Divjak & Tomić, 2011; Gilliam et al., 2017). The principles for building successful (in terms of outcomes) STEM games rely on building on the research and evidence outlined here. Drawing on both the research base and our own experiences designing and implementing STEM games, we propose four broad ideas for designing educational STEM games.

1. *Connect content to gameplay*. This is the primary differentiating factor between gamification and STEM games. The primary activity in a high-quality STEM game is to engage players in STEM practices and activities directly in the game world.
2. *Employ some of the unique STEM game connections*. Basing STEM games on simulations of systems, explorations of scale, and utilization of practices takes advantage of what is unique about STEM games and leverages that for learning.
3. *Support learning through scaffolding and narrative*. One of the challenges with simulations is their stand-alone, wide-open nature. Games can provide situated learning as players experience the necessary structures, the guiding experience, and building identity through engaging with the game's narrative.
4. *Collect data and provide feedback*. The fact that so much of what players do in STEM games is built on models and systems in turn provides the perfect opportunity to collect data about what players are doing and provide students and their teachers with feedback.

Educational games that follow these principles can provide interactive, engaging experiences in STEM fields to a wide range of students (Mayo, 2009). The affordances of educational games have great potential to help kids learn STEM material; however, additional research is needed to solidify that link (Boyle et al., 2016; Clark et al., 2011; Giessen, 2015; Girard et al., 2013). Despite considerable resources invested in, and research about, educational games, there are still many foundational questions that remain unanswered (Clark et al., 2014; Sherry, 2015). The field of educational games will benefit from theoretically grounded and empirically supported frameworks to understand how features of games relate to learning, how to select educational goals that can be best addressed by games, and the types of goals high-quality games should achieve.

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17 Digital Games as Language-Learning Environments

Jonathon Reinhardt and Steven L. Thorne

Learning, Language, and Games

Human development can be catalyzed by many factors, for example through adaptation to novel social, symbolic, or material conditions, opportunities for individual and collaborative interaction and problem solving, and consequential decision making. Learning also develops as a function of large volumes of effortful engagement, which makes relevant the importance of motivation, positive affect, cultivation and maintenance of social relationships of significance, and, of course, the pleasure in pursuing forms of activity that are complex and difficult to master. Digital gaming, and more broadly the role of ludic engagement as a form of developmentally productive activity, brings together many of these factors.

Extending back to the earliest days of computing and the advent of public access to the internet, and over the past decade in particular, there has been a mercurial rise in interest in play environments that take the form of digital games. Catalyzed by advances in hardware and networking technologies, the maturation of digital games has been accompanied by exponential growth in the types and genres of games available and the number, diversity, and geographical distribution of players. The global video game industry is growing at an unprecedented rate, as are profits. An April 2018 report (Newzoo, 2018) forecast that 2.3 billion gamers worldwide would spend US$137.9 billion in 2018, an increase of 13.3% over 2017. The October 2018 release of *Red Dead Redemption 2* earned more in its opening weekend (US$725 million) than the biggest opening weekend for any film (US$640 for *Avengers: Infinity Wars*) (Crecente, 2018). In 2016, 20 countries had game industry revenues over US$500 million (Statista, 2018), and according to the Wikipedia entry on game developers, video games are developed in over 40 countries (Reinhardt, 2019). It thus stands to reason that video games are produced and translated in the common languages of the top global markets. Moreover, because global interest in new game titles does not dictate distribution and availability of those titles in multiple languages, it also stands to reason that millions of people around the globe play games not in their first language but in an additional one, often English or another language of wider communication.

Because of its global spread across many language and culture populations and a plurality of devices, from mobile phones to personal computers and gaming consoles, gaming has spawned complex and heterogeneous online communities and linguistic and cultural practices (Thorne & Black, 2007). Games are, de facto, learning environments that are intentionally designed to guide players to higher levels of skill and challenge over time. Increasingly, the use of gaming features and mechanics has been leveraged for educational purposes in what has been described as the *serious games* movement, and games designed for second and foreign language (L2) learning continue to become available in greater numbers. In part because some genres of recreational digital games are language intensive, language researchers and educators have also explored the use of commercial off-the-shelf digital games (primarily multiplayer games) as sites for L2 use and learning. In contemporary scholarship within fields such as education, applied linguistics, and world languages, online gaming has emerged as a central focus for technology-related research and pedagogical innovation.

The following review of existing L2 gaming research, pedagogical innovation, and commentary on design is organized and presented through a lens of eight game-based L2 learning affordances: (1) contextualization and linguistic environment, (2) time and iterative play, (3) shelter for practice, (4) goal orientation and purpose, (5) languaging and sense-saturated coordination, (6) identity performance, (7) independence, and (8) autonomy. Following a general introduction and descriptions and examples of L2 cases of digital gaming, game-based L2 learning is presented according to research addressing the aforementioned affordances, which subsequently informs an agenda for future research, pedagogy, and design. Limitations, challenges, and opportunities conclude the chapter.

What Is Game-Based L2 Learning?

Online games represent a pedagogical shift from models of learning based on information presentation and toward theories of human development that emphasize engaged problem solving, collaboration, social interaction, and, in some cases, competition. Recent research has argued that some forms of gaming, particularly multiplayer genres of online gaming, present developmentally fecund environments for the learning of specialized literacies, scientific reasoning, contextualized engagement with content knowledge, high-level problem solving (Bogost, 2007; Gee, 2003, 2007; Grimes & Feenberg, 2009; Nardi & Kallinikos, 2010; Plass, Homer, & Kinzer, 2015; Squire, 2006, 2008; Steinkuehler & Duncan, 2008), and even provide dynamic opportunities for the development of leadership abilities (Thomas & Brown, 2009). The general research on gaming for learning (and particularly in language-rich and communication-intensive environments) supports continued exploration of gaming for language learning on three fronts: (1) to investigate naturalistic language use and language learning in recreationally oriented gaming environments, (2) to assess language learning processes, efficiencies, and outcomes in gaming environments designed for L2 learning, and (3) to draw from all available evidence in order to pedagogically amplify language learning from recreational gaming experience (for example, by coupling it with traditional instructional methods; see Wouters et al., 2013) and inform the development or iterative improvement of existing L2 game environments. Following the terminology used in this volume, we use the term "game-based" learning throughout the chapter. However, we wish to acknowledge Reinhardt and Sykes's (2012) distinction between using "game-based" to refer to the use of L2 learning-purposed games, "game-enhanced" for the use of vernacular (i.e., noneducational, generally recreational) commercially produced off-the-shelf games, and "game-informed" for the application of game mechanics to educational processes and contexts (including what is commonly referred to as gamification; for a discussion in L2 contexts, see Reinhardt & Thorne, 2016).

L2 classroom instructors have long used games and simulations as pedagogical techniques. Since they first appeared more than 40 years ago, digital games have been used for both informal and formal L2 learning (Hubbard, 1991; Jones, 1982; for a review, see Peterson, 2010). While the more recent rise in popularity of commercial digital games was initially met with considerable skepticism, both within language teaching and more broadly in education and among the public, many have come to recognize games' potential as motivating, authentic, cognitively and linguistically complex, and effective learning environments (Gee, 2003, 2007; Squire, 2005; Thorne, Black, & Sykes, 2009). In their review article on trends in serious gaming for education, Young et al. (2012) state that games designed to teach languages "may be the most effective use of educational computer gaming to date" (Young et al., 2012, p. 74). Evidence of interest in digital game-based and game-enhanced language learning is now well represented in book-length treatments (Mawer & Stanley, 2011; Reinders, 2012; Reinhardt, 2019; Sykes & Reinhardt, 2012), special issues of journals (Cornillie, Thorne, & Desmet, 2012; Reinhardt & Sykes, 2014), and special-interest groups at international computer-assisted language learning conferences (e.g., EuroCALL and the Computer-Assisted Language Instruction Consortium, CALICO).

In addition to game-based L2 environments and apps, it is relevant to reiterate that gamers around the globe often do not have access to games in their first language and therefore play them in an L2, learning the language informally and in a just-in-time manner in order to play (Chik, 2012; Sundqvist & Sylvén, 2012; Thorne, 2008a, 2010; Thorne & Fischer, 2012). Vernacular games are authentic and lived-in cultural artifacts, and, in this sense, online gaming is a socioliteracy practice involving interaction and engagement, which can lead to meaningful, contextualized, and goal-directed L2 use and learning. (Certain genres of gaming communication may be limited in their transferability to other contexts, however. See Ensslin, 2012; Thorne, Fischer, & Lu, 2012.) Designs associated with adventure, narrative-rich role-play, and collaborative multiplayer games are recognized as affording the dynamics of L2 learning; accordingly, the most researched genre in the field is massively multiplayer online games (MMOs) (Peterson, 2016). At the same time, as L2 educators and material designers have recognized the motivating and developmentally productive qualities of vernacular games, they have also sought to create game-based learning environments and applications specifically for L2 learning. Some have been created by designer-instructors for local and experimental uses (Cornillie et al., 2012), and a few have been developed by educational publishers and made commercially available—for example, McGraw-Hill's *Practice Spanish: Study Abroad*—although they have yet to be thoroughly evaluated.

Reflecting the diversity of theory in the field of second-language acquisition (SLA), researchers and L2 pedagogical designers have used structural-behaviorist, psycholinguistic-cognitive, and sociocultural frameworks, along with commensurate pedagogical methods (Filsecker & Bündgens-Kosten, 2012; Peterson, 2010; Reinhardt, 2019; Thorne, 2012). Research has recognized parallels among principles of game design and gameplay on the one hand and SLA, L2 pedagogy, and language use and learning on the other—for example, in quality of the linguistic environment, goal orientation, availability of linguistically mediated interaction, feedback, and contextualization through narrative framing and event-driven scenarios (Purushotma, Thorne, & Wheatley, 2009; Sykes & Reinhardt, 2012). Related evidence-based intervention projects are exploring the design of game-based L2 learning informed by processes and principles of language development (Cornillie, 2017). More recently, researchers have employed the ecological concept of affordance (Gibson, 1979), or "possibilities for action that yield opportunities for engagement and participation, that can stimulate intersubjectivity, joint attention, and various kinds of linguistic commentary" (van Lier, 2004, p. 81), for understanding the L2 learning potentials of particular game designs and environments. From an ecological perspective, various combinations of designed game mechanics, when enacted in certain gameplay contexts, can be understood to afford dynamics that correlate with L2 use and learning (Reinhardt, 2019).

Examples of Game-Based L2 Learning

Game-based and game-enhanced L2 learning can occur in a variety of settings (e.g., informally in the wild, in experimental conditions, and in more formal classroom environments), using both vernacular and educationally designed games. In this section, we introduce various studies that describe gameplay and its relation to L2 learning. Synoptically described, available research includes accounts of formal L2 classroom interventions using recreational games (Miller & Hegelheimer, 2006; Reinhardt, Warner, & Lange, 2014), descriptive and quasiexperimental studies of educational and recreational gameplay (Scholz & Schulze, 2017; Zheng, Young, Wagner, & Brewer, 2009), surveys of gamer orientations to plurilingual communication, language use, and play style (Thorne & Fischer, 2012), the degree of "willingness to communicate" in online gaming environments (Reinders & Wattana, 2011, 2014), descriptions of the design and implementation of mobile game-based L2 learning applications (Holden & Sykes, 2011; Thorne, 2013), analysis of the linguistic complexity of online game worlds as an enabling condition for L2 learning (Thorne et al., 2012), and accounts of design-based experiments focused on particular game mechanics associated with known L2 learning affordances (Cornillie et al., 2012).

An early example of the use of a single-player recreational game for language learning involves *The Sims* (and its many iterations). A game that simulates the activities and responsibilities of everyday life, *The Sims* is produced in a number of languages. In an informal assessment of *The Sims* as a foreign language learning tool, Purushotma (2005) found that the vocabulary and tasks comprising the game were highly aligned with the practical everyday content of conventional foreign language curricula: clothing, food, household items, furniture and functionally specific rooms in a house, occupations, transportation, neighborhood environments, family relations, and the like. Purushotma suggests that the difference between instructed foreign language learning and a game like *The Sims* is that exposure to the target language in the latter is always linked to carrying out tasks and social actions, which concomitantly embeds vocabulary and constructions in rich associative contexts. Formal classroom contexts can support form-meaning-function association and learning in games like *The Sims* through the use of materials and instructor mediation that focuses learners' attention on particular level-appropriate language and content. For example, Ranalli (Ranalli, 2008; see also Miller & Hegelheimer, 2006) created supplemental materials for ESL learners playing *The Sims* that focused on basic vocabulary in the game. This study found statistically significant improvement of vocabulary scores after a lesson structure of briefing, gameplay with materials, and debriefing, reflecting a traditional approach to simulation-based L2 pedagogy (Crookall & Oxford, 1990) adapted to current digital games (Meskill, 1990).

The research literature shows numerous examples of informal game-enhanced L2 learning in recreational multiplayer gaming environments. One of the earliest empirical cases examining multilingual communication occurring in *World of Warcraft* described an interaction between a speaker of English living in the United States and a speaker of Russian living in Ukraine (Thorne, 2008b). The two were playing near one another when the Ukrainian communicated the following text message: "ti russkij slychajno?" (are you Russian by any chance?). The American replied with a question mark and then asked, "What language was that?" This initiated 140 turns of dialogue that began with information exchange regarding spatial location and mutual interests in gaming and popular culture. The primary language used was English, but three languages (including one instance of a Latin aphorism) were used in total. The transcript illustrated a number of positive assets for language learning, such as natural and unscripted interaction, reciprocal alterations in expert status, explicit self and other correction at the level of linguistic form, extensive repair sequences when communication broke down, development of a positive affective bond (adding one another as in-game friends), and exhibited motivation by both parties for learning the other's language. Exposure to and use of multiple languages within *World of Warcraft* (and other online multiplayer games, such as *Dota 2* and *Fortnite Battle Royale*) can be frequent, depending on realm and play partners, and many anecdotal accounts of language learning through multiplayer gaming have been reported in online player forums (see Thorne, 2010, for examples). Related research on young Swedish students found that L2 English learning was strongly correlated with frequency, volume, and types of informal online gaming, particularly in the area of L2 English vocabulary (Sundqvist & Sylvén, 2012, 2014).

Research shows that game-enhanced L2 learning also occurs under more formal or quasiexperimental conditions. For example, Dixon and Christison (2018) report on the interactions of three L1 Mandarin players they had play *Guild Wars 2* in English. In their analysis of the in-game text chat, the researchers found evidence of comprehension checks, form-focused feedback, and negotiation for meaning—constructs correlated to L2 learning in psycholinguistic accounts of SLA. In another example, Rama, Black, van Es, and Warschauer (2012) explored how L2 proficiency and gaming literacies interacted in multiplayer *World of Warcraft* gameplay. They found that Spanish learners with high gaming literacy were able to leverage their gaming skill in order to maximize affordances for communication with Spanish-speaking players, while learners with higher L2 Spanish proficiency but low gaming experience found it much harder to learn how to play an unfamiliar game and to interact meaningfully with other gamers in their L2. Informal game-enhanced L2 learning can even occur in "couch"-based multiplayer situations. For example, Piirainen-Marsh and Tainio (Piirainen-Marsh and Tainio, 2009; see also Piirainen-Marsh and Tainio, 2014) show, through ethnomethodological conversation analysis of the interactions between two copresent adolescent L1 Finnish players playing an English-language version of *Final Fantasy X*, that playing a game in an L2 affords opportunities for what they call "other repetition," or mimicry and language play, with the dialogue produced by nonplayer characters in the game, which builds language awareness and ultimately contributes to proficiency.

Finally, as game development becomes more available to amateur designers, more L2 teaching professionals are creating, testing, and researching games for particular learner needs and contexts. For example, in their hybrid mobile game, Berns, Isla-Monte, Palomo-Duarte, and Dodero (2016) layered structure-focused learning activities with more collaborative game elements, first teaching the players the vocabulary they would need to play the game through traditional minigame (grammar and vocabulary) type activities and then having them come together and role-play a pervasive murder mystery game. Results based on surveys and player data showed increased learner motivation and positive learning outcomes.

Game-Based L2 Learning

Second-language acquisition is a contentious field comprised of diverse and competing frameworks, but virtually all approaches acknowledge the importance of the quality of the linguistic environment and opportunities for meaningful and contextualized communicative engagement as primary contributors to developmental outcomes. To begin with a few preliminary observations that describe the theoretical perspective of learning taken by the authors, humans can be seen as open systems, with the implication that development arises as a function of interaction within historically formed, and dynamically changing, social, symbolic, and material ecologies (de Bot, Lowie, Thorne, & Verspoor, 2013; van Lier, 2004). When viewed this way, learning of whatever kind cannot be clearly separated from life experience. Rather, life activity and development form an "ensemble" process that is enacted along a brain-body-world continuum (Spivey, 2007). This open system principle entails a number of ideas, one of which is that human action is mediated by symbolic tools and material artifacts, physical and social surroundings and dynamics, and sedimented histories of social practice (Vygotsky, 1978; for its application in L2 research, see Lantolf & Thorne, 2006). This perspective is particularly relevant to assessing technology-mediated communicative and cognitive activity since the meditational means at hand—a computationally enabled gaming environment, for example—potentially transform the morphology of human action in ways that affect developmental processes and outcomes (Thorne, 2016).

An ecological perspective on L2 learning (van Lier, 2004) recognizes language and learning as involving situated, contextualized processes that are both cognitive and social. It offers the useful concept of affordance (Gibson, 1979), an ecologically available action potential for language use and learning that can be aligned with theories of game design relating designed mechanics and player dynamics (Hunicke, LeBlanc, & Zubec, 2004). Similar to an L2 learning affordance, a game mechanic or design feature can be understood as an actionable dynamic or behavior. The potentiality and contingent nature of the concept fit with the unique quality of games as ergodic and emergent; that is, that they must be played to be fully realized, and each time they are played, outcomes may differ. While research on game-based L2 learning can be categorized according to its alignment with particular SLA theoretical frameworks, the design-informed lens we use here focuses on a number of game-related L2 learning affordances: (1) contextualization and linguistic environment, (2) time and iterative play, (3) shelter for practice, (4) goal orientation and purpose, (5) languaging and sense-saturated coordination, (6) identity performance, (7) independence and spatial mobility, and (8) autonomy.

Contextualization and Linguistic Environment

A major affordance for L2 learning in many games is that coherent narratives are used to contextualize game mechanics, allowing the learner-player to associate form, meaning, and function through interaction with multimodal representations. As with aforementioned studies of *The Sims*, this affordance is manifest in simulation games where players can manipulate or interact in the L2 with everyday, familiar objects, spaces, and actions. When players are primed with certain vocabulary before playing, through the use of supplemental materials, retention rates are higher (Ranalli, 2008) and learners retain knowledge of primed vocabulary longer than for incidental and nonprimed vocabulary (Shintaku, 2016). Franciosi (2017) found that an experimental group exposed to vocabulary in a simulation game in addition to regular instruction retained vocabulary knowledge statistically significantly longer as measured by uses of the language in a debriefing writing task.

In many multiplayer game genres, players are exposed to copious texts during gameplay, for example quest texts, in-game text communication, and paratexts (or attendant discourses) such as game-external online strategy and lore websites that are often contrapuntally used during play. In contemporary research on language acquisition, usage-based investigations (Ellis, 2002; Tomasello, 2003) have underscored the importance of the quality of the social and linguistic environment as it relates to developmental trajectories. Characteristics such as input frequencies, linguistic complexity, and language-mediated opportunities for joint attention and meaningful engagement are understood as foundational to language learning. A fundamental question then is, what is the linguistic quality of recreational game-associated texts? Selecting *World of Warcraft*, the most popular MMO at the time, Thorne, Fischer, and Lu (2012) used corpus and computational linguistic methods to assess the linguistic complexity of game-generated "quest" texts that guide player actions and of the game-external texts that were designated by players as central to gameplay (i.e., particular strategy websites). All texts examined were in English, with the presumption that this information would be relevant for L2 learners of English and potentially would also be generalizable to analogous texts in other languages. Linguistic complexity can be broadly defined as the range and sophistication of language forms and structures. Thorne et al. (2012) assessed the linguistic complexity of multiple corpora of texts related to *World of Warcraft* using four measurement types: (1) readability, (2) lexical sophistication, (3) lexical diversity, and (4) syntactic complexity. A synopsis of the findings is that representative samples of quest texts and external websites, analyzed at the level of individual sentences, reveal mean average complexity measures that approximate a secondary school reading level suitable for students aged 13–17 years. Closer analysis, however, revealed a polarized distribution of sentences that clustered in two extremes—those that are short and syntactically simple and those that are long and syntactically highly complex. The graphical representation of the distribution of sentences for each corpus type showed a right-skewed (or complexity-weighted) "U" pattern. This indicates that there is considerable variability in sentence complexity levels within the texts, with the most complex levels of sentences occurring with the greatest frequency. This secondary distributional analysis illustrated that, in quotidian gameplay, gamers encounter a high proportion of lexically and syntactically complex sentences. To summarize, the linguistic input from written texts, both internal and external to the game, subserves language learning.

In addition to the empirically assessed high linguistic complexity of game-related texts discussed earlier, research by Steinkuehler and Duncan (2008) illustrates that *World of Warcraft* discussion forums foster "scientific habits of mind." Analyses of nearly 2,000 forum posts related to *World of Warcraft* revealed that 86% of the entries displayed "social knowledge construction" rather than "social banter," 65% treated knowledge "as an open-ended process of evaluation and argument," more than half the posts included evidence of systems-based reasoning, and 10% showed scientifically precise model-based reasoning (Steinkuehler & Duncan, 2008, p. 539).

Time and Iterative Play

A second affordance is that game designs can manipulate normal time progression and may allow players to do so as well, often for the purpose of completing an in-game task. Repeatability is an affordance for any sort of practice-based or mastery learning, but L2 processing in particular can be afforded by slowing, repeating, or rephrasing input or by enhancing it with captions or other forms of annotation. In addition, fluency can be developed by prohibiting learner control of pacing and requiring language production or performance under time pressure. Because of this, some have argued that genres such as simulations, adventure, interactive fiction, and turn-based strategy games are optimal for L2 learning, especially if they allow self-pacing and incorporate features such as captions and repeatability and do not penalize players for taking their time (Reinhardt & Thorne, 2016; Sykes & Reinhardt, 2012). On the other hand, multiplayer collaboration under time pressure, as in newer cooperative and multiplayer survival games, may afford learning because they push or force spontaneous language production (Reinhardt, 2019).

Empirical research on the affordances of time have focused on the limits of working memory, especially in action and multiplayer games. DeHaan, Reed, and Kuwada (2010), for example, had pairs of L1 Japanese English learners—one playing, one watching—play a dance game and found that those actively playing the game retained fewer new vocabulary items than those watching. They speculate that the working-memory capacity of the players was exceeded as they were forced to learn the rules of the new game while playing it, while the observers could focus on the vocabulary of the game. In a related study using *WarioWare* minigames, DeHaan and Kono (2010) likewise found that vicarious observers of gameplay learned twice as much vocabulary as those playing, suggesting that the cognitive load of playing while simultaneously learning an L2 may be overly taxing until routine skills associated with gameplay become familiar and automatized. The implication is to recognize that in multiplayer games and games where pacing cannot be controlled, L2 learners may be cognitively taxed if they are unfamiliar with the game. Pedagogically, these studies argue for continued experimentation with collaborative play on a single device or screen, and even consideration of Twitch streaming and related eSports events as potential areas for research.

Games as a Shelter for Practice

A third affordance for L2 learning is the self-contained quality of games as a shelter for practice and space for anonymized participation. In MMOs and game-related affinity spaces, L2 learner-players can encounter like-minded communities with more interest in gaming than linguistic fluency. In these environments, players may find speakers of a variety of languages as well as opportunities for transcultural and translingual interactions (Thorne, 2008b) but can mask their true identities if desired. Because the stakes for failure in a game task may be low and anonymized, learner-players may be more willing to take risks. For other learners, however, the prospect of interaction with native and expert speakers can raise anxiety and negatively impact willingness to communicate and risk taking, which are recognized as pivotal to successful L2 learning (MacIntyre, Dörnyei, Clément, & Noels, 1998). For those students, sheltered game contexts may be more appropriate. Reinders and Wattana (2014), for example, found that Thai learners of English produced more language and reported more willingness to communicate when completing tasks in a modded version of an MMO run on a LAN in comparison to the open public version of the game.

Goal Orientation, Purpose, and Feedback

A fourth affordance is related to the parallels between evidence-informed practices in L2 pedagogy regarding learning task design and the goal-directed nature of, and feedback mechanisms designed into, game tasks (Purushotma et al., 2009). In short, L2 learning is more likely when the language is used for purposes meaningful to the learner. A well-designed L2 learning task requires using the L2 as the means to complete it rather than having it serve as the direct target of instruction. This mirrors how learning in well-designed games is an epiphenomenon of play (Arnseth, 2006) rather than the point of play. A well-designed game makes clear or discernible to players the object and purpose of any game task, and its outcome should be integrated and relevant to ongoing gameplay (Salen & Zimmerman, 2004). As Gee (2003, 2007) has suggested, digital games are engineered to enhance human experience in the realms of "control, agency, and meaningfulness" (Gee, 2007, p.10), a condition that helps explain why players invest such significant amounts of time in gameplay. For most individuals, it can require hundreds of hours of playtime to access advanced levels of game content, and while there can be considerable repetition in the types of challenges presented, depending on the game in question, scenarios also become continually more complex as a player ontogenetically develops and a concomitant expansion of tools and strategies emerges to support continued progress. As Gee (2007) has argued, these features catalyze developmentally productive processes that bring together pleasure and learning through a focus on difficult and engaging goal-directed activity.

A related parallel is how feedback is provided; in evidence-informed L2 instruction, correction should be timely and relevant, and evaluative only when meant to be summative. In well-designed games, linguistic feedback is just in time and in the right amount and periodicity, so as not to interfere unnecessarily with gameplay. For L2 learning games, feedback should be integrated and focused on linguistic meaning but also on form. In a design-based study of 83 high school and university students, Cornillie and colleagues (Cornillie, Clarebout, & Desmet, 2012; Cornillie & Desmet, 2013) found that L2 learning-game players prefer, and perform better with, explicit feedback on linguistic form. Based on this research, the authors suggest integrating explicit feedback into game design through interactive conversations with nonplayer characters that give pragmatically appropriate communicative responses to mistakes as opposed to the alternative of recasts or overt punitive actions.

Languaging and Sense-Saturated Coordination

A fifth major affordance that gaming offers L2 learners is the opportunity for languaging, a verbal form of the noun meaning to align and interact linguistically with others in real-time to negotiate and achieve shared goals. In recent scholarship that unites processes of language use with sociocultural inventories of semiotic potential, Thibault (2005) has described language as a "multi-modal contextualizing activity which is embedded in an ecosocial semiotic environment and which integrates diverse space-time scales" (Thibault, 2005, p. 123). This approach contests what has been termed the "code approach" to language as an abstract system independent of human action (Linell, 2009; Love, 2004). By space-time scales, Thibault is referring to an important and often unacknowledged ontological distinction between first-order languaging and second-order language, where first-order languaging describes real-time communicative activity between interlocutors that is irreducible to the "formal abstracta" that is the preoccupation of descriptive linguistics. Importantly, first-order languaging is constrained by "second-order patterns emanating from the cultural dynamics of an entire population of interacting agents on longer, slower cultural-historical timescales" (Thibault, 2011, p. 2). When applied to the analysis of dialogic interaction, the implication is that first-order languaging is phenomenologically primary and that second-order language constitutes historically sedimented semiotic patterns and lexicogrammatical resources that constrain what is possible and enable probabilistically likely and pragmatically effective choices within a given communicative encounter. In the design of L2 learning environments, a main objective is to provide conditions conducive to first-order languaging. In game-enhanced L2 learning research, Zheng and colleagues (Zheng et al., 2009; Zheng & Newgarden, 2017; Zheng, Newgarden, & Young, 2012) have examined complex languaging dynamics in social MMO gameplay in terms of human players' negotiation for meaning, alignment, and value realization, and also between players and nonplayer characters in the environment. The implications are that languaging opportunities can be cultivated and supported through progressive quest design, random and complementary resource distribution (i.e., structured unpredictability), player and nonplayer character interaction, and the role specialization mechanics that many multiplayer, role-playing, and cooperative games incorporate. As game technologies allow multiplayer and cooperative team designs to be at the center of new game types, such as cooperative survival sandbox games (e.g., *Don't Starve Together; Fortnite Battle Royale*), new affordances for languaging and "sense-saturated coordination" emerge as well (Steffensen, 2013, p. 196).

Identity Performance

Sixth, successful L2 learning requires investment in the performance of identity, often through semiotic work that involves reconciling and integrating multifarious, sometimes conflicting, perspectives, cultures, and understandings of the world. Simply committing to playing games in another language for entertainment and/or for serious (i.e., learning) purposes is itself an investment in new forms of practice that can potentially contribute to the development of linguistic and intercultural competence. For example, Warner and Richardson (2017) show through qualitative case study techniques how a German learner developed as he took on the role of guild leader in a formal classroom game-based activity, struggling with his Bartle gamer style results as a "killer" (Bartle, 1996) but ultimately reconciling his "gamer" identity with that of "learner." Thorne (2012) demonstrated that intercultural encounters are bound to occur in massively multiplayer game worlds and that they can lead to serendipitous opportunities for L2 and culture learning as well as the development of plurilingual textual identities that propagate across related media (e.g., game worlds, strategy websites, and fandom communities). Jeon (2015) showed that Korean English learners developed broader awareness of English as a global language and new identities as L2 English users by playing *League of Legends* on international, English-language servers. The experience motivated her participants to reassess their understandings of the reasons for learning to use English. Finally, research by Rama et al. (2012) indicated that in multiplayer game worlds, a player's gaming expertise and shared goals and affinities were at least as important to other players as language proficiency, although accent and oral language proficiency may play more of a role today in voice chat than when text chat was more dominant.

Independence and Spatial Mobility

A seventh affordance for L2 learning involves game-based uses of mobile devices. A mobile game for L2 learning (e.g., *DuoLingo* and *LingroToGo*) can be played when and where convenient for learners and provides them with agency and control. Here we focus specifically on the use of location-aware mobile devices supporting games designed to be played in particular locations. Locative media, such as smartphones, are ubiquitous across much of the world (Frith, 2015) and have opened up new possibilities for interfacing embodied and virtual experience. Applications of locative media, for example place-based mobile augmented reality (AR), are now used in a variety of educational content areas and have been shown to provide learners with opportunities for investigation-based learning, location-situated social and collaborative interaction, and embodied experience of place (Holden et al., 2015; Squire, 2009; Thorne & Hellermann, 2017). Place-based AR mobile gaming typically involves guiding or drawing players toward specific physical spaces by using GPS locations on a digital map. The AR dimension involves orienting participants' attention to particular places or relevant features of the landscape and then augmenting their experience with semiotic resources, information, tasks, or prompts, with the intention of creating an embodied and experiential in-the-world dynamic for participants.

One of the first games to use AR technology for language teaching (L2 Spanish) is *Mentira*, a place-based mobile game set in a Spanish-speaking neighborhood in Albuquerque, New Mexico, where learners work together to solve a prohibition-era murder mystery. While playing the game, students complete a jigsaw-puzzle-style activity in which each player receives different clues, prompting collaboration to complete the task. Analysis of play records (Holden & Sykes, 2011) found that integrating the orientation tutorial into the game narrative resulted in more time on-task. Additionally, students reported being motivated by their place-based experience in a Spanish-speaking neighborhood, which for some participants included interacting with local residents in Spanish. In another study, Perry (2015) describes an AR game for French called *Explorez*, a quest-style game similar to *Mentira*. Perry reports that students made efforts to speak in French while playing the game and indicated that at times students' efforts to stay in the target language resulted in a "sociocultural learning effect" (Perry, 2015, p. 2313) in which students who were more advanced supported the group with needed vocabulary and correction of language errors. In a study of the place-based AR game *Guardians of the Mo'o*, Zheng et al. (2018) illustrate how "place evokes a learner's effort for making meaning and realizing values through embodied action, collaboration and coordination" (Zheng et al., 2018, p. 55). Adopting an ecological perspective, Zheng et al. argue that "experiencing place is critical for learners to break away from institutional norms and previous thinking patterns in order to develop skilled linguistic action in actual events that lead to prospective actions" (ibid.). This is illustrated via wayfinding activity, such as anchoring their next actions in what is physically present in their environment.

ChronoOps is a quest-type mobile AR game, created and located in Portland, Oregon, that is currently available in seven languages, including English (Thorne, 2013). Participants play the role of an agent from the future. The game begins by describing that in the year 2070, the planet has suffered massive environmental degradation and they (the player-agents) have been sent back in time in order to learn from the green technology projects that are evident on and around the university campus. *ChronoOps* was designed as a series of open-ended and intentionally underspecified tasks with the pedagogical motivation of having players construct their actions as agents in interaction with the game's goals and content. In research on *ChronoOps*, Thorne, Hellermann, Jones, and Lester (2015) used ethnomethodological conversation analysis to investigate how groups of L2 English students sharing one smartphone orient to the device and the information it displays, develop practices for wayfinding, and use talk to bring shared attention to features of their physical surroundings. This research emphasizes the importance of how the game moves the language experience out of the classroom and how the group dynamic around one device influences students' interactional practices. In related research, Hellermann, Thorne, and Fodor (2017) describe the complex interactions associated with the literacy event of reading aloud during mobile AR gameplay, illustrating that collaborative practices for playing the game that involved reading emerged and consolidated over the duration of the activity. Addressing the hypercontextualization and place-based potential of AR, Thorne and Hellermann (2017) analyzed video data of *ChronoOps* gameplay and describe how problems in understanding, as well as moving forward to the next action, are often enmeshed with and supported by the immediate physical environment. Their analysis demonstrates the relevance of embodied and distributed approaches to human activity, illustrating that participants utilize gaze, gesture, vocalizations and talk, pointing, and embodied deixis, in an orderly manner, to coordinate virtual-digital (iPhone) and sensory-visual information, to navigate to the next location, and to complete the oral narration tasks comprising the game. In a study focusing specifically on L2 acquisition, Sydorenko, Hellermann, Thorne, and Howe (in press) employ the widely used construct of language related episodes (LREs) as a unit of analysis. This research illustrates that the mobility and contextual embeddedness of AR tasks create opportunities for just-in-time and situationally driven vocabulary learning, with implications for continuing AR game design and pedagogical structuring of hypercontextualized approaches to language learning.

Autonomy in and through Informal Practices

The eighth and final affordance is related to the preceding discussion in that mobile and geolocation technologies allow more spatial freedom and independence and hence also afford opportunities for autonomous, informal social practices, even when they are part of a structured educational course of study. When L2 learning in much of the world is thought of as a school subject rather than an organic human activity, providing the resources to autonomously learn an L2 effectively is often an afterthought (though see Little & Thorne, 2017). A digital game is meant to be played in a self-contained way, insofar as once it is launched it should be, for the most part, learnable and playable without any additional support from its creators. At the same time, gamer communities engage in extensive attendant literacy practices around games that extend and support autonomous play. For L2 gaming, however, there may be additional need for linguistic support and pedagogical mediation, and there is demand for games that integrate support for L2 users and learners in the form of optional captions and subtitles, repeatability and time control features, and access to glosses, dictionaries, or other resources, some of which are produced as modifications to the gaming environment by the player community itself.

The reality is that millions of individuals learn L2s informally in order to play games, but often these practices go unrecognized and unsupported by practitioners of L2 pedagogy, such as teachers, and SLA research. Research shows the complexity and diversity of these informal practices, especially as they involve considerable interaction with gamer communities in multiple languages (Chik & Ho, 2017; Vasquez-Calvo, 2018). For example, in a case study, Vasquez-Calvo (2018) describes how a first-language (L1) Spanish participant in several online affinity spaces focused on gaming and game translating to informally develop proficiency in English. The focal participant autonomously contributed to a variety of forums, offering microtranslations and corrections to other translations of English-language games, taking on a variety of roles (e.g., gamer, reader, fan translator) and engaging in a wide range of literacies that involve enhanced linguistic and IT skills.

An Agenda for Research, Pedagogy, and Design Focused on L2 Learning Dynamics

SLA recognizes several major theoretical perspectives on language learning, each of which can be aligned with ontologies of language and literacy, implicating particular L2 pedagogies and game designs. First, a structural view understands language as structure that is acquired through translation, transfer, and repetitive practice, aligning with behaviorism and both grammar-translation and audiolingual L2 teaching methods. In the design of game-based L2 learning, repeated exposure, positive and negative reinforcement, explicit feedback on form, and translation-focused activities (e.g., as with popular language learning app *DuoLingo*) align with structural views. The second perspective, psycholinguistic-cognitive, recognizes the active role of cognitive processing and memory in the individual mind of a learner. Aligned with this perspective, the input-interactionist view of SLA (Long, 1983) maintains that input must be partially comprehensible, gaps noticed, and meaning negotiated among interlocutors in order to facilitate acquisition. In game-based learning design, a psycholinguistic-cognitive view implicates providing opportunities for immersion in partially comprehensible narratives, noticing and production of meaningful language use, and interaction and negotiation of meaning. The sociocognitive perspective includes a range of theories (Atkinson, 2011) that encompass Vygotskian sociocultural theory, language socialization, identity-focused theories, and Bakhtinian dialogism, all of which, in generally commensurable ways, emphasize social-relational dynamics and learning as a function of changes in forms of participation as foundational to language use and development (Lave & Wenger, 1991; Sfard, 1998). In game-based L2 learning design and research, these approaches implicate facilitating multiplayer interaction and collaboration, role-play, learning as a culturally shaped activity, and participation in player communities.

In addition to drawing implications from a priori theoretical stances, the aforementioned discussion of affordances may offer a cohesive research agenda focused on the L2 learning dynamics that emerge in and around gameplay as specific designs interact with player characteristics (e.g., age, linguistic proficiency level, gaming experience) and contextual variables (e.g., classroom environments, experimental conditions, informal recreational play). Research that focuses on the relationships between specific game design features and player languaging behavior in recreational gameplay (including their associated socioliteracy practices) can ultimately inform the design of game-enhanced pedagogies (e.g., supplemental materials and soft modding designed to amplify L2 learning. Moreover, these findings can ultimately inform the design of educational-game–based L2 learning environments and pedagogical practice.

Contextualization

With regard to the contextualization affordances of game spaces, specific research questions might ask how incidental and intentional learning processes, narrativization, interactivity, and identity contribute to form-meaning-function associations and learning. In emerging AR and virtual-reality contexts, for example, there may be heterogeneous player responses to its potential for deep situational and emotional immersion, and thus cognitive and memory loads may be so high as to inhibit learning, while for other players or with different event scenarios and tasks, it may support learning. This new context for research on L2 learning, especially given the prevalence of smartphone usage by individuals and groups for a wide array of informational, communicative, and navigation practices, warrants continued investigation.

Time

Experimental studies using cognitive and working-memory load theory (DeHaan, Reed, & Kuwada, 2010) may offer insight into how game mechanics can scaffold language comprehension and production, accuracy, and fluency, by means of game task design and feedback provisions. There is a need for descriptive studies examining how L2 gamers in the wild leverage time affordances and to what extent that manipulation (e.g., to repeat or translate a dialogue) might impede or augment game enjoyment.

Shelter

One potential research area is to examine how well-designed games push players to challenge themselves and increase proficiency while building autonomy, without engendering overdependence on scaffolding. Research on more formal game-based instruction might inquire how game modifications, learning task parameters, and supplemental materials can serve to scaffold and provide a sense of shelter, raise willingness to communicate, and lower anxiety through their design, for example by providing opportunities for "graceful failure" (Plass, Homer, & Kinzer, 2015).

Goals

There is a need for more research on how the interface design of a game—whether recreational or educational in its purpose (understanding that these are not mutually exclusive categories)—supports learning (i.e., supports orientation toward L2 learning goals and uses supplemental resources without being overly didactic, which is a problem with educational games). Research might ask to what extent (i.e., when and how) a game should offer glosses for vocabulary; player control of annotations, translations, and captions; repeatability and control of time mechanics; or access to external metalinguistic resources (e.g., grammar aids, pragmatics strategies). Features that support using a game for learning are typical of some titles in some genres, and some games provide access to help features and player guides within their interfaces, while others make it more difficult or rely on the player's use of resources external to the game. Additional empirical and usability studies correlating types of language-learning supports and forms of feedback with learning outcomes is needed, a process that has been initiated in intelligent computer-assisted language learning environments (Heift, 2013; Heift & Vyatkina, 2017).

Languaging and Collaboration

An overarching question implicated by research asks how game-based languaging is afforded by task parameters, which relates to learning mechanics as described in Plass, Homer, Mayer, and Kinzer (chapter 1 in this volume) (e.g., whether they are open ended or single outcome), by task function (e.g., whether they involve planning, problem solving, brainstorming, or strategizing)—or by task configuration (e.g., whether they are collaborative, cooperative, conjunctive, or competitive). There is a considerable amount of research on task-based teaching and learning to draw on that already explores how task design relates to L2 learning affordances but not under gameplay conditions. A group collection task in an MMO might afford opportunities for language use that are quite different from those in a survival game where time pressure compels players to differentiate and assign roles, or in a mystery-themed escape game where players must coordinate actions and collaboratively deduce the meanings of clues. In these varying conditions, unique interactional discourses emerge that warrant empirical investigation.

Identity

Storymaps (spatialized narration with maps; e.g., Neville, 2015) or *alterbiographies* (emphasizing story generation emerging in gameplay rather than scripted story telling; e.g., Calleja, 2011), among many other game-enabled actions and affordances, develop in unique narrative trajectories for each player each time a game is played, but how these develop and integrate, especially insofar as they involve L2 language use, has not been well investigated. Researchers might ask how players engage in identity work and play, and how this is reflected in expressions of alterbiographies—a game journal, an interview, or a debriefing, for example. Interventions might use serious or educational games that present opportunities to experience events or contexts from different perspectives and assess learner development of intercultural competence or emotional literacies. Research might explore how particular design mechanics and contextual dynamics afford perspective taking and value realization, and how those interact with identities and backgrounds external to the game.

(In)dependence

The affordances for L2 learning offered by network, mobile, AR, and other very new digital technologies (at the time of this writing) for new kinds of place- and time-independent and place-bound learning implicate new possibilities for research, instruction, and design, especially when viewed in conjunction with affordances for languaging and social collaboration.

Autonomy

Learners increasingly need autonomous learning skills to make critical use of the wide variety of game-based L2 learning tools available—knowing how to learn both on their own and with others in intercultural interaction, as well as how to self-direct and assess their own learning. Research should continue to explore game-based L2 learning practices to identify how formal instruction might complement and support them. Perspectives on games as media (Hjorth, 2011), socially attuned and ecological frameworks, and microinteractional learning sciences approaches are especially useful for such research. The attendant discourses, paratexts, communities, and socioliteracy practices associated with gaming defined broadly offer rich sources and spaces for inquiry, and as new practices emerge, so do new opportunities for research.

Limitations, Challenges, and Opportunities

Speaking to game-based and game-enhanced language learning, Sykes and Reinhardt (2012) observe that there remains an outstanding need for large-scale studies that include “psychometric instruments, pre-post measures of learning outcomes, systematic observation and analysis of real-time gameplay, and perceptive measures such as interviews, focus groups, and surveys" (Sykes and Reinhardt, 2012, p. 113). The design and implementation of such large-scale mixed-methods studies would allow researchers to more finely assess game-based L2 language use and learning from multiple perspectives, to assess and compare developmental trajectories of participants within, and potentially across, game genres, and to measure the effects of particular forms of gameplay on language retention. Such research could also inform language instructors' choice of recreational digital games for L2 learning and the design of L2 learning-purposed games, and could potentially contribute to amplifying game-based and game-enhanced learning outcomes through instructional mediation and activities. To our knowledge, such mixed-method, large-scale studies have not yet been carried out, leaving open many prospects for future research.

Much of the current empirical research on game-based L2 learning and pedagogy does not include participant numbers large enough to generate statistically significant findings. In addition, there is a dearth of interaction between L2 practitioners and researchers and game developers, who may lack understanding of how SLA principles interact with game mechanics. Moreover, educational publishers are necessarily invested in products that look to the consumer like they are effective, whether or not their effectiveness has been thoroughly evaluated. Last but not least, research on L2 use and learning in 3-D multiplayer environments is simply challenging for a number of reasons. The spatial and semiotic complexity of game worlds makes necessary a wide and highly complex array of methodological approaches, including multimodal analysis and ethnomethodological attention to the sequential organization of player actions, interactions, and engagement with texts and artifacts in the game environment. Additionally, virtually all popular multiplayer games include attendant strategy, lore, and fandom paratext sites, the use of which can be interwoven with real-time gameplay, presenting challenges to data collection. As suggested by Plass et al. in reference to game-based learning at large, "the integrated viewpoints of cognitive, motivational, affective, and sociocultural perspectives are necessary for both game design and game research in order to fully capture what games have to offer for learning" (Plass et al., 2015, p. 278).

At the same time, there is growth in smaller-scale, qualitative studies of informal game-enhanced learning, often using ethnomethodological and discourse-analysis approaches, as well as studies reporting on the development and application of local, customized game-based applications. These studies, some of which have been reported on here, take innovative approaches to combining research methodologies, L2 learning theories, and game design principles, forging new ground. An underexplored but promising area involves gaming literacies, in particular design literacies (Reinhardt, Warner, & Lange, 2014; Zimmerman, 2007) and their relationship to L2 learning. Innovative examples of gaming literacies research and pedagogical interventions exist (Butler, Sumeya, & Fukuhara, 2014; DeHaan, 2011; Lacasa, Martínez, & Méndez, 2008; Steinkuehler, 2007), but there is ample space for continued exploration of gaming as a translingual and intercultural global practice (Warner & Richardson, 2017). Gaming literacies can be instructionally facilitated by designing and building games (Howard, Staples, Dubreil, & Yamagata-Lynch, 2016), by critically considering the function of games and game culture in society, and as learning environments and affinity spaces that are organized in a distinctly different way compared to conventional instructional models. As new technological innovations lead to new game types and genres, new areas for exploration and research open; for example, language acquisition research is incipient in regard to multiplayer cooperative games, virtual- and augmented-reality games, pervasive and urban games, and hybrid game genres. Attendant practices such as gamer fandoms (Sauro, 2017; Vasquez-Calvo, 2018) are just now being investigated, and nothing in the literature has yet reported on eSports or Twitch streaming, which by all accounts are highly translingual and global practices. In sum, opportunities for innovation in game-based L2 learning—theoretical, methodological, pedagogical, and design—abound.

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18 Games for Enhancing Cognitive Abilities

Pedro Cardoso-Leite, Augustin Joessel, and Daphne Bavelier

Action Video Games Have Broad Impact on Cognition

The ease with which humans learn and adapt has long been recognized. Yet, a vexing issue in the field of training is the high specificity of learning. Examples of such extreme specificity can be found in virtually every subdomain in psychology, spanning educational psychology, social psychology, developmental psychology, clinical psychology, and human factors. In the visual perception domain, for example, training individuals on a Vernier acuity task—which requires people to estimate whether two horizontal bars are truly aligned—will improve their performance. Yet, if asked to perform a slightly different version of this same task, such as judging vertical rather than horizontal bar alignments, their performance will be indistinguishable from that of a naive participant (Fahle, 2005). Similarly, in the domain of human memory, experienced *Go* players can reliably recall briefly presented *Go* displays. However, these *Go* experts don't have high memory performance when tested with *Gomoku* displays—despite the two games using the same board and pieces (Kareev & Eisenstadt, 1975). This is a vexing issue, as for all practical considerations from education to patient rehabilitation, generalization beyond the exact task used for training is necessary to ensure an impact on daily life (Schmidt & Bjork, 1992). A key question then concerns the possibility of identifying a training regimen that enhances performance more broadly.

Research over the past 15 years provides evidence of a beneficial impact from playing action video games (AVGs) on different subdomains of cognition, from perception to top-down attention, or spatial cognition (Bediou et al., 2018). We note that too few studies investigated reasoning or problem-solving abilities, which leaves open the question of whether AVGs impact higher-level cognitive skills typically linked to academic achievements. In this literature, AVGs mostly map to first- and third-person shooter games, as these were the first reported to positively impact attentional control (Green & Bavelier, 2003). Since then, the ecosystem of video games has evolved dramatically, and other video game genres with similar game mechanics may also affect cognition for the better, such as real-time strategy games (e.g., *Starcraft*, as in Glass, Maddox, &

Love, 2013; see also Dale & Green, 2017a; Kim et al., 2015), driving games (e.g., *Need for Speed*, as in Wu & Spence, 2013), as well as possibly action role-playing games (e.g., *Skyrim*, *Final Fantasy*, or *Mass Effect*), given their inclusion of shooter mechanics, although no such studies exist at this time (for a review, see Dale & Green, 2017b).

A number of studies contrast self-declared habitual AVG players with individuals having little to no video game experience. These cross-sectional studies provide socially relevant information as to the cognition of individuals who choose to play AVGs. AVG players are typically defined as people who play first- or third-person shooter games for at least three hours per week and have done so for at least the last six months. AVG players so defined have better vision, as indexed by better contrast sensitivity, higher crowding acuity, or less masking, compared to non–video game players (Achtman, Green, & Bavelier, 2008; Green & Bavelier, 2007; Li, Polat, Makous, & Bavelier, 2009; Schubert et al., 2015). Within this literature, non–video game (NVG) players are individuals who seldom engage in casual video gameplay, playing less than three hours per week, irrespective of game genre. Compared to NVG players, AVG players exhibit enhanced attentional control, whether measured through visual search efficiency, recovery from inaccurate cueing, or more efficient filtering of distractors during demanding tasks (Hubert-Wallander, Green, & Bavelier, 2011; Wu & Spence, 2013). Benefits have also been noted in mental rotation, visuospatial working-memory tasks, or task-switching paradigms (Spence & Feng, 2010; Strobach, Frensch, & Schubert, 2012).

Recent meta-analytic work by Bediou et al. (2018) on the impact of AVGs on cognition documents the cognitive profile of habitual AVG players, contrasting them with NVG players on seven domains of cognition. A positive impact of about half a standard deviation (Hedges's g=0.55) across all these domains of cognition was noted in an analysis that included close to 3,800 participants. Among these domains, attentional control, spatial cognition, perception, and multitasking are enhanced most reliably. Weaker but still significant enhancements were observed for inhibition and verbal cognition, highlighting the relatively broad impact of AVG play on cognition. Note that no firm conclusions could be made regarding the relationship between AVG play and problem solving, because of limited sample sizes, which calls for more studies in future work.

Not All Video Games Have an Equally Broad Impact on Cognition

Cross-sectional studies provide a useful means for investigating which cognitive domains AVG play may impact. Yet, to rule out population selection bias or similar confounds and truly assess the causal impact of AVG play on cognition, intervention studies are needed. In these studies, participants are randomly assigned to either the experimental group, which will be trained with action video games, or the control group, which will be trained with nonaction video games, and their performance is evaluated before and after training (figure 18.1). Both types of video games are commercially available and successful entertainment video game titles, but they use very different game mechanics. While the video games for the experimental group are shooter games, control video games have included puzzle games such as *Tetris*, social-simulation games such as *The Sims*, turn-based strategy games such as *Restaurant Empire*, or visuo-motor coordination games such as *Balance*. Using this type of randomized controlled trial (RCT), the action-trained group has been reported to improve more than the control-trained group from pretest to posttest (Green & Bavelier, 2012). Such interactions between training game and testing time are central in establishing the causal impact of AVG play on cognition.

Specifically, a second meta-analysis by Bediou et al. (2018) probed the causal impact of action video games by combining 609 participants from intervention studies, all following the same RCT active control design as detailed earlier. For these, the impact of AVG play on cognition was also significant, although expectedly smaller (Hedges's *g*=0.34), given the shorter exposure and the comparison to an active group also playing video games. In line with the results from the cross-sectional meta-analyses, the greatest impact of action video game training was found on attentional control and spatial cognition, with encouraging signs for perception. The impact of AVGs on the domains of inhibition and problem solving could not be tested because of small sample sizes, and its effect on multitasking and verbal cognition remained unreliable in the face of

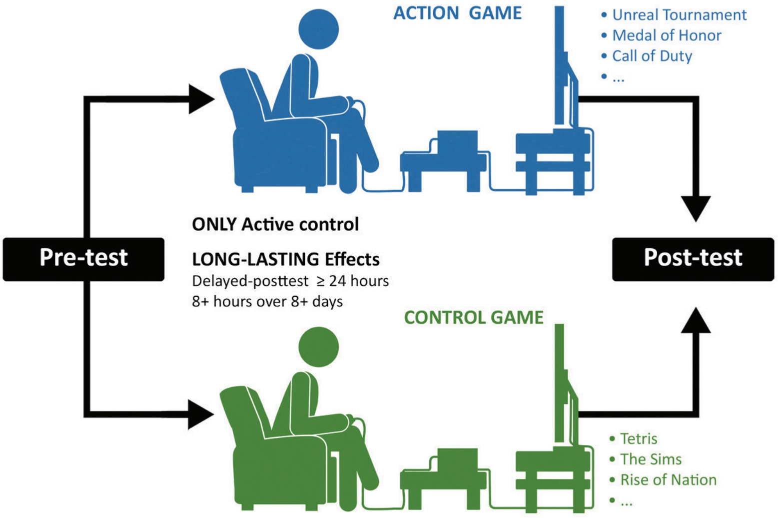

Figure 18.1
Design of intervention studies contrasting the impact of action vs. control video games on cognition.

again relatively low sample sizes, even if in the right direction. It is likely that not all aspects of cognition will be equally impacted by AVG play; yet, it remains that their impact is rather wide compared to the typical high specificity of learning.

An added and important characteristic of all these intervention studies is that they contrast commercially available games from the action genre on the one hand and other slower-paced, less attention-taxing video game genres, such as puzzle games, social simulation games, or turn-based strategy games, on the other. The finding that playing action video games enhances cognition more than playing these other game genres provides important pointers as to the key game features that support broad cognitive enhancements. Before turning to this topic, however, we review the cognitive processes that appear to mediate such broad cognitive impact after playing action video games.

Attentional Control Improvement May Underlie Broad Cognitive Enhancements

Attentional control is the ability to flexibly allocate processing resources as task demands change, all the while staying focused on the task at hand and ignoring sources of noise or distraction. The proposal that attentional control facilitates performance in a variety of domains is central to many models of executive functions (Diamond, 2013; Miyake & Shah, 1999), whereby along with attentional control, inhibitory processes and cognitive flexibility are seen as key enablers of performance on most cognitive tasks. Accordingly, a large body of literature has documented the role of executive functions in enhanced performance, from education science to auditory perceptual learning. Executive functions as measured by the planning scale of the cognitive assessment system (Naglieri & Das, 1997) have been positively linked to academic achievement in a large sample of children (*N*=2036; Best, Miller, & Naglieri, 2011). Similarly, albeit in a very different domain, executive function as measured by the N-back task has been linked to the ability to learn an auditory discrimination task. More notably, Zhang et al. went beyond a correlational approach and demonstrated that working-memory training facilitates future auditory learning (Zhang et al., 2016).

In the case of AVGs, attentional control has received the most support as a mechanism of action for the relatively broad changes in cognition they induce (Green & Bavelier, 2012). Accordingly, many studies report enhanced attentional control, whether processing resources have to be allocated over space, in time, or to objects, after AVG play. Enhancements in attentional control are among the easiest to induce, with changes seen after only 10 to 12 hours of AVG play. In contrast, changes in vision have typically been observed after 30 or more hours of training (Green & Bavelier, 2007; Hutchinson & Stocks, 2013; Li et al., 2009; Schubert et al., 2015). Studies using brain-imaging techniques such as steady-state visual evoked potentials (SSVEPs) indicate that AVG players more efficiently suppress irrelevant, potentially distracting information (Krishnan, Kang, Sperling, & Srinivasan, 2013; Mishra, Zinni, Bavelier, & Hillyard, 2011). Better attentional control enables AVG players to extract task-relevant information from their environment more efficiently, allowing them to make better-informed decisions—at least when it comes to sensing their surroundings—and thus show higher performance (Green, Pouget, & Bavelier, 2010).

The view that attentional control is key to performance enhancement is certainly not new. Ahissar and Hochstein (1997) proposed that attention is central for abstracting across task requirements and developing higher levels of representation, thus counteracting the high specificity so typical of learning. By downplaying irrelevant information and instead highlighting task-relevant information, attentional control also acts as a filter on the information that guides behavior. Accordingly, the frontal-parietal network of attention is seen to act through feedback connections on earlier cortices to facilitate processing through both a combination of response enhancements and distractor suppression (Lewis, Baldassarre, Committeri, Romani, & Corbetta, 2009; Roelfsema, van Ooyen, & Watanabe, 2010). Burgeoning evidence is pointing to changes in the frontal-parietal attentional system in action video game players. Bavelier, Achtman, Mani, and Föcker (2012), for example, reported activation of the frontal-parietal network as task difficulty and attentional demands increased. Interestingly, this network was recruited *less* among AVG players than among non-AVG players—a result that might suggest that AVG players can allocate attention more automatically, which is in line with the behavioral evidence supporting that action gaming enhances attentional resources (for a review, see Green & Bavelier, 2012). Krishnan et al. (2013) also compared AVG players to role-playing video game players (RPG players) on a top-down attentional task and reported stronger distractor suppression abilities among the former. Among AVG players, they observed that SSVEP responses to unattended stimuli correlated with behavioral performance to the attended stimuli, suggesting that stronger distractor suppression abilities support a more efficient processing of task-relevant signals. The strongest correlations with behavioral performance were observed for electrodes placed over the right parietal and temporal cortices, which are involved in the monitoring of relevant information in unattended locations (Krishnan et al., 2013).

Overall, these results consistently indicate that the effects of action video games can at least be partially described as an enhancement of top-down attentional control systems. Which features in action video games may be responsible for these effects is the topic of the following sections.

Game Features That May Foster Broad Cognitive Impact

Video games are currently our most advanced virtual environments, and although they are designed mostly for entertainment, the literature reviewed here suggests that some specific categories of these games are effective in improving cognition. One strategy to further our understanding of cognitive training is therefore to contrast effective games with ineffective ones and attempt to reverse engineer which game features are action-game specific and could therefore underlie the observed behavioral benefits. This was the approach used by Green, Li, and Bavelier (2010), who described action video games as sharing a (1) fast pace (transient events, fast-moving objects), (2) high perceptual, cognitive, and motor load in the service of accurate action, (3) temporal and spatial uncertainty, and (4) a strong emphasis on peripheral processing.

This list came in handy when researchers wanted to train cognitive abilities in children but couldn't use the age-inappropriate action games that have been tested with adults. Franceschini et al. (2013) used this list to classify child-appropriate minigames within *Rayman Raving Rabbids* into "action" or "non-action" and used those games in a training study for the experimental and control groups, respectively (see tables 18.1 and 18.2; two representative games are further described here and in figure 18.2). Their results show that 12 hours of playing action minigames improved attention and reading among their dyslexic children compared to 12 hours of playing the nonaction minigames from the same *Rayman Raving Rabbids* video game title. These results demonstrate the usefulness of studying video games and their mechanics for scientists interested in cognitive training.

A second approach focuses on the cognitive processes that may be worth training rather than on the game features themselves (e.g., Anguera et al., 2013; Goldin et al., 2014; Homer, Plass, Raffaele, Ober, & Ali, 2018; Parong et al., 2017). Anguera and colleagues designed a video game to train multitasking in older adults and observed improvements not only in multitasking but also in other cognitive tasks that were greater after multitasking than after single-task training (Anguera et al., 2013). To give a more recent example, Homer et al. (2018) created a child-friendly minigame targeting task switching that was then used in a training study. In agreement with their hypothesis, training task-switching with the game led to improvements in task-switching as measured by standard task-switching paradigms. The strategy of focusing on cognitive processes to design cognitive training interventions had proven successful in the past, sometimes even yielding benefits well beyond the specifics of the intervention program (i.e., relatively far transfer, as in Anguera et al., 2013; Au et al., 2015; Goldin et al., 2014).

This approach clearly has its merits. It is driven by theory around cognitive processes and how they interact and therefore supports a better understanding of the fundamental cognitive processes that need to be involved to foster more general cognitive enhancement. Yet, whether training individuals on a set of cognitive tasks may reliably induce cognitive enhancement in trainees remains highly controversial. This approach has been most studied in the context of training executive functions. The *CogMed* software—a collection of working-memory minitasks for children—has arguably been studied the most. It shows both promising results concerning inattentional behavior

Table 18.1
List of *Rayman Raving Rabbids* minigames classified as *action games* and used in an intervention study by Franceschini et al. (2013)

Minigame name	Game mechanics
Bunny Hunt	FPS-like game where the player shoots plungers at rabbits that can appear anywhere on the screen and attack the player
Shake Your Booty	Similar to *Guitar Hero*; fast-paced rhythm game where the player presses keys in sync with events on the screen
Bunnies Are Addicted to Carrot Juice	FPS-like game where the player shoots carrot juice at rabbits coming unpredictably out of the water and attacking the player
Bunnies Can't Shear Sheep	The player shears sheep by tracking their motion and applying rapid, simple action sequences on them.
Bunnies Rarely Leave Their Burrows	Whack-a-mole game
Bunnies Are Bad at Peek-a-Boo	Typical "red-light, green-light" game. Move quickly when the enemy is not looking and stop when it is.
Bunnies Are A-mazing	Race through a maze viewed from the top as quickly as possible but also accurately enough to avoid hitting the walls.
Bunnies Have a Great Ear for Music	Visual and auditory search task: among a group of singing bunnies, find which one is not singing correctly.
Bunnies Don't Use Toothpaste	Whack-a-mole game
Bunnies Like to Stuff Themselves	The player needs to rapidly draw shapes outlined on the screen.
Bunnies Are Slow to React	3-D balancing puzzle game requiring both speed and accuracy
Bunnies Don't Like Being Shot At	The player shoots at moving objects and has to predict trajectories for the shots to actually hit the targets.
Bunnies Never Close Doors	Whack-a-mole game
Bunnies Can't Jump	The player needs to jump rope at varying, externally driven speeds while ignoring the many distractions occurring on the screen.

Note: Although not everyone may agree with each of these classifications, the games provide an interesting approach to studying the effects of gaming on cognition.

(Holmes et al., 2010; Spencer-Smith & Klingberg, 2015) and disappointing effects when it comes to cognitive skills or academic achievement (Gathercole, Dunning, & Holmes, 2012; Morrison & Chein, 2011; Roberts et al., 2016; Shipstead, Hicks, & Engle, 2012). In the subdomain of task-switching, there is a long history of training individuals on a specific task-switching task and having them show improvement in that very task and its overall speed of task execution. But most studies report failure to reduce the task-switching cost itself; that is, the ability for participants to reduce the cost of switching from one task to another on demand (Baniqued et al., 2015; Minear & Shah, 2008).

Table 18.2
List of *Rayman Raving Rabbids* minigames classified as *nonaction games* and used in an intervention study by Franceschini et al. (2013)

Bunnies Don't Give Gifts	Race against the clock where the player controls only the speed with rapid, repeated actions
Bunnies Like Surprises	Slow-paced game where the player directs a bunny in space using sound
Bunnies Can't Fly	Race game where the player controls only the speed with rapid, repeated actions
Bunnies Have Natural Rhythm	The player has to run toward and hit all the characters that are highlighted with the same color.
Bunnies Don't Milk Cows	The player has to repeatedly do the same simple movement as quickly as possible.
Bunnies Can't Play Soccer	The player does quick, repeated movements to run toward a ball, presses a key to hit the ball, and then controls its trajectory to bypass the goalie and score.
Bunnies Are Heartless with Pigs	The player walks slowly through a maze guided by sound feedback.
Bunnies Can't Slide	The player aims at a unique and static target.
Bunnies Are Not Ostriches	Slow-paced game where the player has to carefully control a small UFO and pull bunnies from the ground
Bunnies Don't Understand Bowling	The player throws a barrel as if bowling and controls its trajectory to hit a group of static bunnies.
Bunnies Have a Poor Grasp of Anatomy	A collage of a rabbit is rotated rapidly, and lights are turned off. The player has to reconstruct the rabbit from pieces in the orientation in which it was last seen.
Bunnies Don't Know What to Do with Cows	The player does repeated movements to increase speed and presses a key to throw a cow.

Note: Although not everyone may agree with each of these classifications, the games provide an interesting approach to studying the effects of gaming on cognition.

Thus, training specific cognitive constructs in the context of narrowly defined tasks or minigames has not yielded as much cognitive enhancement as could be expected from reviewing the cognitive processes that appear foundational to cognition and learning more generally (Owen et al., 2010).

Finally, a third approach attempts to relate action video games to learning principles gleaned from the cognitive neuroscience of learning or from computational learning models (Bavelier, Green, Pouget, & Schrater, 2012). The goal here is not simply to describe the differences between action and nonaction video games but also to relate these differences to learning theories and ask why these differences matter. This is the approach that we pursue here. We present a nonexhaustive list of game features we think are important for enhancing cognition. While these features are present in varying proportions in all commercially successful games, it appears that action video games are characterized by a particular combination of these feature values, which might explain their greater effects on cognitive enhancement. We outline why those specific feature values in action video games are important in light of computational learning principles and hypothesize that the cognitive benefits observed after playing action video games are caused by these game features because they:

(a) target general-purpose cognitive abilities, in particular processes that enhance attentional resources, promote flexible cognitive control, and support increased processing speed;

(b) favor model-based learning by encompassing many regularities in a rich enough structure to encourage the player to extract patterns from the game and form generative models that can be applicable in various situations; and

(c) provide relevant variability to keep participants engaged, drive learning, and limit automatization, or the highly specific mastery of the exact gameplay being trained.

In order to spell out a research agenda, in the next subsection we propose six main design principles and discuss how they may favor each of these three key principles for promoting cognitive enhancements.

Being in the Zone of Proximal Development—Adequate Scaffolding of Level Difficulty

Games are fun only to the extent they are challenging yet doable. Successful games therefore have to be initially easy enough not to discourage any players and then challenge players continuously to keep them engaged and interested. Scaffolding in video games is perhaps best illustrated with the game *Portal*, a first-person perspective video game where the player has to solve puzzles that involve physics and teleportation—the player uses a portal gun to open entry and exit points to teleport across space. Interestingly, a large part of the game is structured as a sequence of puzzles separated as discrete test chambers. These puzzles are of increasing complexity and build on knowledge acquired in earlier test chambers. For instance, early on, the player has no portal gun (test chamber #00) but learns about the existence of portals. Then the player learns that the portals are created by a portal gun, and the player acquires a gun that can only control one portal (entry or exit portal; test chamber #02), the other being determined by the game. It is only much later that the player can control both the entry and exit points for teleportation (test chamber #11; see https://theportalwiki.com/wiki/Portal_Test_Chamber_11). This scaffolding strategy keeps players engaged, as initial puzzles are very simple and the subsequent ones are only slightly more difficult and thus appear solvable to players. Importantly, this scaffolding ultimately gets players to solve very complex problems, which they most likely would not have been able to solve had they not been trained on simpler ones first.

In psychology, the notion of scaffolding is closely related to the concept of *zone of proximal development* introduced by Lev Vygotsky (1978). It characterizes the range of abilities a student may reach given appropriate external support. Providing adequate and personalized learning experiences—not too easy, not too hard—is thought to be a critical component for optimizing learning. The need to personalize difficulty for learning is supported by substantial experimental evidence (Takeuchi, Taki, & Kawashima, 2010), yet it remains a major challenge in the educational setting.

Adapting difficulty levels to individuals has become such a clear factor for learning that some studies use as a control intervention the same game or task as for the experimental group, with the exception that the difficulty is scaffolded only for the experimental group (Klingberg et al., 2005; Pedullà et al., 2016). It is generally the case that the game with the scaffolding in difficulty yields greater cognitive benefits than the game where the difficulty level is fixed at a low, nonchallenging level. It does not follow that scaffolding and adapting difficulty is sufficient to yield broad cognitive benefits, even if it is necessary. The difficulty in *Tetris*, for example, depends on the player's performance—yet *Tetris* has been used as a control game in many intervention studies based on action video games (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Strobach et al., 2012).

What matters then is what dimensions or processes the scaffolding is applied to. This point is perhaps best illustrated by Anguera et al. (2013), who trained older adults on one of two difficulty-adapted modes of the same game—*NeuroRacer*—which comprises two component tasks. One group played the game in multitasking mode and was required to perform well on both subtasks, while the other group performed each subtask in isolation. Although both groups were put in equally challenging situations in the sense that the speed of each task maintained participants at around 80% correct, cognitive benefits were observed only for the multitasking group. Similarly, Glass et al. (2013) trained participants on two versions of the same commercial real-time strategy game (*StarCraft*) and assessed the impact of those games on cognitive flexibility. Both versions were equated for difficulty, as the difficulty rate was adapted to maintain a win rate around 50%. However, in one version (full), the player had to control two friendly bases and handle two enemy bases, while in the other version (half) the player controlled only one of each within a smaller game space. It is only for the full version, which is richer in structure and requires a greater degree of multitasking, that cognitive flexibility improvements were observed. Such outcomes illustrate that maintaining the learner through increased challenges is not at the core of broad cognitive enhancement; rather, enforcing the challenge load on cognitive resources, cognitive flexibility, and speed of processing is of the essence.

Reward Structures and Adequate Feedback

Many researchers have highlighted the importance of immediate feedback in video games for learning as well as to support flow (Gentile & Gentile, 2008; Csikszentmihalyi & Csikszentmihalyi, 1992). However, video games typically have complex reward and feedback structures that are not yet well understood. There is full and immediate feedback at a short timescale; for example, when shooting at an enemy, clear signals are given to the player if a shot has hit or missed the enemy. Alternatively, there are also long sequences of actions that form one of many possible paths within the game space, and it is only at the end of such a path, without being told explicitly whether a different course of action would have led to a better outcome, that the player receives a reward. In a game like *Call of Duty*, there are many choices the player can make at any time: whether to attack or not, which enemy to attack, which weapon to use when attacking, and so on. Whether the player succeeds or fails, the player won't be told what alternative actions should have been taken to yield better results—as in chess, the player needs to explore the game space and find it out on their own. More recently, newer generations of video games integrate a variety of feedback and reward signals. Some games show the players a replay of the sequence of the game that led to their defeat or victory, for example. Others, such as *Overwatch*—a team-based, multiplayer, first-person shooter game—allow players to vote for each other, and a player might be highlighted as the "most valuable player" despite being on the losing team.

The field of learning has long highlighted the critical role feedback plays in learning. In fact, the type of available feedback characterizes the main subcategories of learning in machine learning, from full or instructional feedback in supervised learning (i.e., the correct response is provided) to no feedback in unsupervised learning and evaluative feedback in reinforcement learning (i.e., a reward signal is provided to evaluate the quality of a response but not what the best response would have been). To illustrate this point, let's consider the task of classifying images of faces as male or female. In supervised learning, it may be enough to learn a mapping, or discriminative model, between input and output values, ignoring information about the distribution of those values. For example, the learned model may state that if the roundness of the face exceeds a specific value, one should decide that the image is the face of a woman, independently of the values along the wrinkle dimension. If the subsequent task is to determine for the same set of images whether they correspond to a young or an old person, the learner will have to start from scratch and learn a new discriminative model. Alternatively, a learner who initially is not given any feedback (or partial feedback) might nevertheless learn the underlying structure of the space in which the face images live, gaining knowledge relevant to both gender and age discrimination. Then, if subsequently asked to learn to discriminate images based on age, this learner will be able to use the knowledge gained during the gender categorization to speed up learning to categorize by age.

Feedback about the player's actions does not need to be a binary signal—correct or incorrect; it may involve richer signals to evaluate performance. For example, if a student wants to learn which career, A, B, or C, will suit them best, there is typically no way to tell that person which choice is the correct one. By experiencing A, B, and C and gathering rewards from each of them (e.g., working conditions, salary), the student will be able to determine which of these choices best suits them—but there might still be options D to Z that would be even better. This type of situation is the basis for reinforcement learning theory, where rewards, instead of the correct answer, are given at the end of a sequence of actions. Because the optimal solution is not communicated to the player, learning in this context requires exploration of the possibility space through trial and error. Such a process, however, is very time consuming and would require, for instance, going through a level of a game thousands of times to figure out the best sequence of actions to perform. To shortcut this process, players may use their past knowledge and the rich internal representations they have previously built about their world to create templates of the game structure at a fundamental level. These rich internal representations may support generalizable knowledge and allow players to efficiently make predictions and plan future actions within a novel game context.

Because games use complex reward structures and use several feedback mechanisms at the same time, they are likely to simultaneously drive different forms of learning. The forms of learning of most interest to us here are model-free and model-based learning (Daw, Gershman, Seymour, Dayan, & Dolan, 2011; Lee, Shimojo, & O'Doherty, 2014). Model-free learning allows fast acquisition of the learning space through forming direct links between the variables to be learned and the actions they trigger. This process appears facilitated by immediate, complete, and supervised feedback; a weakness of such learning, however, is that it does not allow much generalization to new situations. In the context of gaming, learning the associations between controller buttons and actions in the game is likely to rest on such model-free learning, for example. In contrast, model-based learning by which the learner builds rich internal models to make sense of the learning space allows more graceful generalization but is arguably more challenging to learn. It is understood that only partial, delayed, or even the absence of feedback may bias learning toward model-based learning (Daw, Niv, & Dayan, 2005). More generally, all theories of learning recognize that feedback is an integral part of the learning process; yet, when it comes to the nature and timing of the feedback, it is critical to consider the goal of the video game intervention. Different forms of feedback are likely required whether the goal of the intervention is to speed up learning of a set domain or ensure a form of learning that may generalize to new situations.

While the importance of adequate feedback has been acknowledged, it hasn't yet been investigated systematically within the cognitive enhancement literature. Computational and neuroscience approaches to learning point to reward as a cornerstone of synaptic plasticity and learning (Choi & Watanabe, 2012; Dayan & Balleine, 2002; Schultz, Dayan, & Montague, 1997). In the context of virtual environments such as video games, burgeoning research is being conducted to identify the best feedback mechanisms, with studies indicating faster learning when feedback is provided at a detailed level from the start (Serge, Priest, Durlach, & Johnson, 2013). Yet, depending on whether speed of learning or generalization is valued, the nature of the feedback may have to be drastically altered, as immediate, detailed feedback while enhancing the speed of learning may limit generalization down the line (Goodman, Wood, & Chen, 2011; Schmidt & Bjork, 1992). These results are nicely in line with the learning theories reviewed earlier highlighting the constant tension between speed of acquisition and generalization of newly acquired skills or knowledge (Bavelier, Bediou, and Green, 2018). The appropriate feedback will depend on the stated learning goal. Feedback also appears to alter different aspects of behavior, depending on its positive or negative valence, with negative feedback pushing more for on-line corrections. Indeed, using a brain-training interface, Burgers, Eden, van Engelenburg, and Buningh (2015) established that while negative feedback pushed players to correct their behavior immediately, positive feedback was key to maintaining engagement over the long term. Similarly, gamification of a cognitive task may not have an immediate effect on performance but can increase participants' enjoyment of those tasks (Hawkins, Rae, Nesbitt, & Brown, 2013). However, it is also the case that gamification, and in particular too many sources of feedback, may hinder performance by either cognitively overloading or distracting the player, resulting in *less* cognitive enhancement (Katz, Jaeggi, Buschkuehl, Stegman, & Shah, 2014). Clearly, feedback is a key driver of learning, but it has to be well designed and delivered in a way that is well aligned with the intervention goals to foster cognitive enhancements.

Emphasis on Processing Speed: Pacing

One of the more salient features of AVGs is their requirement to make decisions under time pressure. This notion is certainly closely linked to the speed with which a game unfolds. In *The Sims*, a real-life simulation game, the pace is rather slow and corresponds approximately to the pace of humans' actions in their day-to-day lives (walking, talking, etc.). In action games, on the contrary, it is not uncommon that the player has "supernatural" abilities, moves at very high speeds, teleports from one location to another, or uses their own shotgun to propel themselves several floors into the air. Yet, absolute speed does not really grasp the distinctive feature of pacing we focus on here. For instance, in some games, many irrelevant events occur on the screen without requiring any actions or thoughts from the players. Similarly, some games may be "fast" in the sense that people have to press the same button repeatedly as quickly as possible, and the screen shows many transient events (see table 18.1). In *Bunnies Don't Milk Cows* (shown on the right side of figure 18.2), for example, players have to perform rapid

Figure 18.2
Example of two *Rayman Raving Rabbids* minigames used by Franceschini et al. (2013) as experimental and control games in their intervention study. The game on the left is called *Bunnies Are Addicted to Carrot Juice*. It was one of the games in the action game group. The game on the right is *Bunnies Don't Milk Cows* and was one of the control-group games.

movements under time pressure but don't actually need to look at the screen to succeed. Such games do not require any meaningful real-time cognitive processing in the service of decision making (such as planning or rapid processing of sensory information); as defined here, they would not have a high pace. In contrast, in the minigame *Bunnies Are Addicted to Carrot Juice* (shown on the left side of figure 18.2), players have to direct a stream of carrot juice at rabbits coming toward the player until they eventually disappear. If the player fails to do so and the rabbit reaches the player, the game is lost. As the game progresses, the number of rabbits increases, forcing the player to rapidly move the juice stream from one rabbit to the next in an appropriate sequence. This game stresses speed but also requires planning; thus it is considered fast paced. Figure 18.2 contrasts these two minigames, used as nonaction and action games in the video game intervention study (Franceschini et al., 2013), to further illustrate this key point.

The emphasis on pacing is even more prominent in action games designed for young adults. In action games like *Unreal Tournament* or *Quake III Arena* (i.e., first-person arena shooters), players have to constantly and rapidly move in a 3-D environment as they monitor their surroundings for possible enemies and resources. They have to avoid running into the shooting range of other players and instead try to catch them by surprise. While doing so, they might get caught by surprise and thus have to switch plans from attacking to running away. Players also have to make their actions hard to predict while at the same time trying to predict the actions of others. If an opponent goes through the arena following the same path, the player can wait around and shoot him in the back. We therefore define pacing here as the features of a game that control a player's processing speed (i.e., the number of informed decisions that need to be made and executed per unit of time).

We propose that high pace is a distinctive feature of action video games that drives broad cognitive enhancement. This same feature may also be the reason why a few training studies have documented that real-time strategy games lead to cognitive improvements, whereas low-pace, turn-based strategy games—which might be equal or even richer in complexity—have not (Dale & Green, 2017a; Dobrowolski, Hanusz, Sobczyk, Skorko, & Wiatrow, 2015; Glass et al., 2013). We speculate that to succeed in action video games or real-time strategy games—more than in turn-based strategy games—increased processing speed is required, which might be achieved by developing relevant internal models that continuously process sensory information and make predictions in light of current goals.

Interestingly, a large body of literature documents the central role of processing speed in higher cognition, from intelligence to executive functions or reasoning (Ball, Edwards, & Ross, 2007; Edwards et al., 2002). It is one of the first aspects of behavior compromised in most, if not all, clinical conditions, as well as in normal aging (Pichora-Fuller, 2003; Salthouse, 2000). Keeping the ability to swiftly extract information from the outside world and rapidly process it may be at the core of cognitive enhancement. In accord with this view, playing action video games has been linked to an approximately 10% increase in response speed at constant accuracy levels (Dye, Green, & Bavelier, 2009).

It is important to note that pacing, contrary to speed, should not be defined in absolute terms but must instead be characterized relative to a person's actual abilities and felt time pressure: to be effective, pacing must be tailored to each player's skill level. Inadequately high pace may in fact be counterproductive. The pacing of commercially available AVGs, for example, is tailored for a specific population and is excessively high for older adults who are unfamiliar with gaming. As a result, such commercial titles tend to negatively impact cognition in older adults (Bediou et al., 2018; Boot et al., 2013). Such a result does not imply, however, that the action features are ineffective for brain plasticity in older adults. Rather, it highlights the importance of keeping the pace of the game within the zone of proximal development of the learner—that is, within a doable yet challenging range. From this point of view, learning with video games is similar to learning in any other context and will obey the same general laws (Stafford & Dewar, 2014)—a point that applies not only to pacing but also to all other dimensions reviewed here.

Finally, we note that the combination of complex processing and speed constraints might encourage specific forms of learning that are not necessarily required if either speed or complexity is removed from the equation. An example from motor control theory may illustrate this point. There are many ways to program a robot to reach for an object, but if the robot is to rapidly adapt to a changing environment—such as when objects are displaced during the reaching movement—the programming (or internal models) of the robot needs to handle that constraint. Waiting for the end of the move to process what just happened and decide what to do next is a viable strategy in a static world but not in a rapidly changing one. A key insight from motor control theory is that such real-time control can be achieved by agents continuously making predictions about their environment and the consequences of their actions. Sensory information can then be directly compared to these prediction signals, and if they mismatch, an error signal is generated that can immediately be used to trigger corrective actions on the fly. This idea is encapsulated, for example, in the concept of forward models (Desmurget & Grafton, 2000; Jordan & Rumelhart, 1992; Wolpert & Miall, 1996). Such models are needed to handle structured but not fully determined environments (for which responses cannot be fully automatized) in the presence of high time pressure. Slow-paced but rich environments, on the other hand, may also benefit from rich internal models, but these may be tailored for increased accuracy rather than speed and may not require continuous prediction mechanisms.

Note that we are not saying that slow-paced but rich environments—such as turn-based strategy games—are necessarily ineffective. Rather, they may lead to different behavioral benefits than those observed after playing AVG, such as, for example, a focus on depth of processing rather than efficient decision making. *Portal 2*, for example, is a slow-paced puzzle game that has a rich structure; accordingly, playing *Portal 2* has been linked to improvement in higher-level cognitive functions such as problem solving (Shute, Ventura, & Ke, 2015; but see Adams, Pilegard, & Mayer, 2016).

Information Load and Variability

Games differ in the sheer amount of information they require players to process at any given time. Figure 18.3 describes two games that differ remarkably in this dimension: *Tetris* and *Team Fortress 2*.

In *Tetris*, the complete state of the game is visible, static, and mostly deterministic. All relevant information is displayed on the screen, game elements don’t have lives of their own, and the only random aspect of the game is the identity of the next shape. The player controls a single shape at a time, and there are a limited number of actions a player can perform (mostly rotating shapes and placing them). Thus, overall, the amount of information a player needs to manage to perform the task successfully is rather limited.

In *Team Fortress 2*, on the other hand, players have to manage a huge amount of information. First, the players are part of a team working toward a common goal against another team, which makes coordinating their actions effectively (rather than playing on their own) fundamental. Second, each player also has the choice between nine distinct avatars, each with its own gameplay and organized into three categories (“offense,” “defense,” and “support”), requiring very different skills and play styles. Importantly, for a team to be successful, players need to self-select their avatar so that the team has the right balance of skills to compete against the other team. In addition, there are various maps in which those battles may occur, and having a good grasp of the spatial layout of a map is critical for moving efficiently and acting strategically. Furthermore, the players only have access to partial information about the state space (where exactly are the opponents? who are they? what's their energy and skill level?), and events may unfold irrespective of their actions or perceptions. Finally, most aspects in the game are probabilistic. Some events are highly likely (e.g., an opponent on top of a building is more likely to be a sniper than a suicide bomber), while others vary across time and in ways that are virtually unlimited (e.g., a one-shot "weapon" that becomes available if a player achieves a certain performance level). As such, AVGs constantly require a fine balance between exploiting existing regularities in the game and remaining open to exploring new modes of gameplay.

Thus, although both *Tetris* and *Team Fortress 2* provide proper pacing, *Tetris* does so in a rather limited space as compared to *Team Fortress 2*. In other words, *Tetris* allows much less variability in experiences than *Team Fortress 2* does. The fact that *Tetris* play occurs in a bounded world with a restricted number of states allows automatization; that is, compiling a lookup table that specifies what actions to perform in response to specific game configurations. Computationally, it is most efficient for a *Tetris* player confronted with one of the seven possible shapes (called "zoids" or "tetrominos") in the context of a given board configuration to access the best action sequence automatically from a memory-based lookup table rather than computing de novo which action steps should be taken. Indeed, such automatization alleviates the need for mental computations, which are known to be so taxing that most *Tetris* players, as they develop expertise, engage in the physical manipulation of the shapes (also called epistemic actions) rather than their mental manipulation to solve the task (Clark, 2008; Kirsh & Maglio, 1994).

The key difference between *Tetris* and *Team Fortress 2* concerns the extent to which all aspects of the gameplay may be automatized. The lack of proper variability in *Tetris* as the player progresses allows for automatization of most task processes; this in turn will limit the transfer to other, not directly related, cognitive functions. To illustrate this state of affairs anecdotally, naive individuals may show enhanced spatial cognition skills, such as enhanced mental rotation, after tens of hours of *Tetris* gameplay, yet individuals who are expert *Tetris* players competing in *Tetris* tournaments, after more than 10,000 hours of gameplay, may not have better than normal mental rotation skills except when tested with *Tetris*-like shapes in the context of *Tetris*-like board configurations (Sims & Mayer, 2002). In contrast, the greater variability in *Team Fortress 2* is likely to limit full task automatization and instead keep attentional resources, cognitive flexibility, and inhibition in high demand. The key difference between *Tetris* and *Team Fortress 2* is thus the extent to which automatization can alleviate the need for attentional and/or cognitive load during gameplay.

We note that automatization is fundamental to learning, as the development of automatized action sequences may simplify the task, improve performance, and free cognitive resources for other processes (Schneider, Dumais, & Shiffrin, 1982). Because good games keep people engaged in tasks for extended periods, they will foster automatization of processes. However, if the goal is to maintain load on attention and/or cognitive control—as seems required for cognitive training—the game needs to present enough variability to specifically prevent full automatization or the release of the demand on these processes.

The proposal that control processes and, in particular, attention are central to broad cognitive enhancements is far from novel (Ahissar & Hochstein, 2004; Green & Bavelier, 2012; Roelfsema et al., 2010; Schneider et al., 1982). Video games that lead to the broadest cognitive enhancements exploit the need for attention. In *Bunnies Can't Jump* (as summarized in table 18.1), for example, the player has to jump rope at varying speeds, and all the while bunnies appear and disappear all over the screen, urging the player's attention. Keeping focused on the main task and unperturbed by distraction is the key to succeeding in this game. Because of their high information load, action video games may therefore stimulate not only processing capacity, such as the ability to extract more information from the environment, but also enhanced attention, whether through enhancement of the object of attention or more efficient distractor suppression.

Encourage Model-Based Learning

Efficient cognitive control requires not only efficient attentional control processes, as seen in the previous subsection, but also knowledge to guide these processes (i.e., what is task relevant and what is not) and the ability to use that knowledge on the fly to guide cognition. Handling complex environments may require building rich internal models that can describe relevant parts of the environment with a manageable number of parameters (Braun, Mehring, & Wolpert, 2010; Kemp & Tenenbaum, 2008). Video games contain a lot of structure, whether through hierarchically structured categories of weapons, situation-specific acoustic environments (e.g., background music indicating imminent danger), coherent visual assets (e.g., to highlight which doors in a game can be opened and which can't), or statistical properties, such as the typical location of enemies in the environment. Understanding that structure makes it easier to perform well in the game and highlights which aspects of the game are relevant and which are not (Botvinick, Niv, & Barto, 2009).

However, understanding structural properties alone may not be enough to affect performance positively: incoming information needs to be interpreted using that understanding, and this process may be costly in resources. This idea is perhaps best illustrated with the distinction made earlier between model-free and model-based learning in recent human reinforcement learning literature (Daw et al., 2011) and, in particular, the two-step reinforcement learning task. In this task, participants make two successive choices (hence, two steps). In the first step, participants decide whether

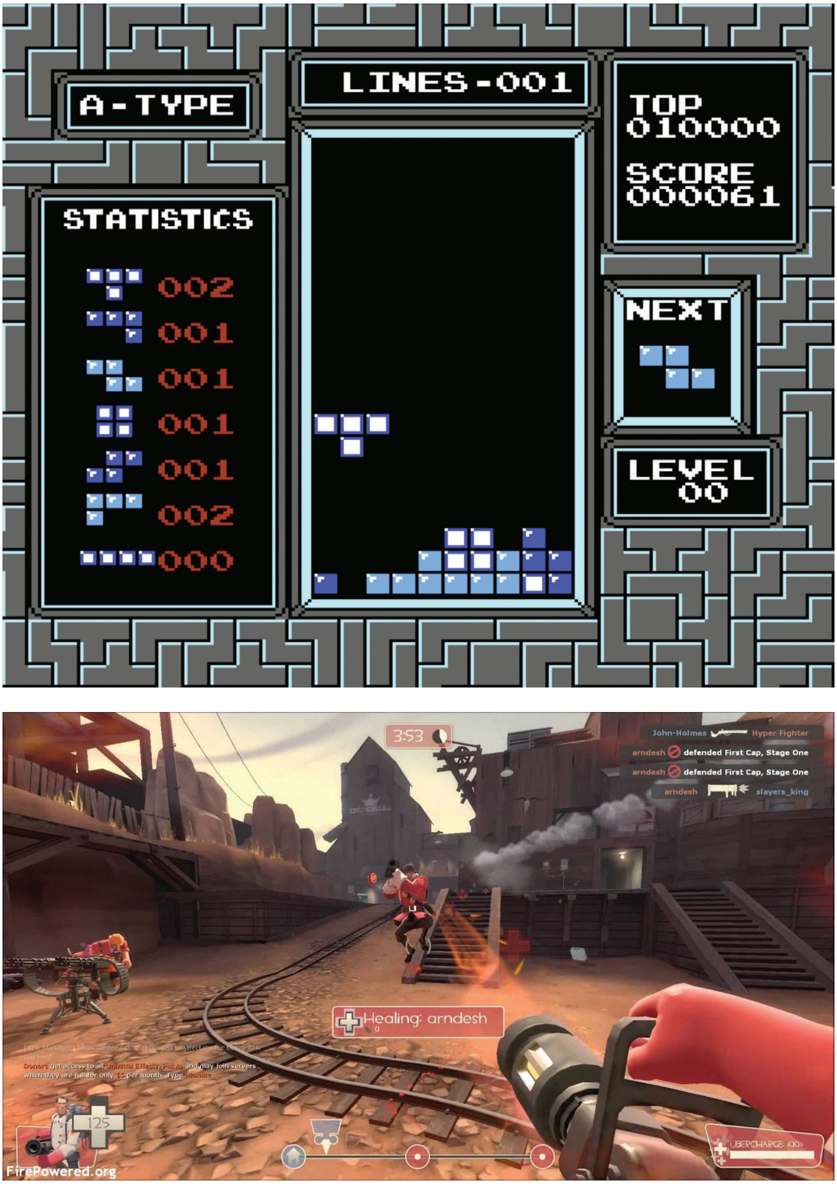

Figure 18.3
The top panel presents a screenshot of *Tetris* where players have to stack up shapes in order to form complete horizontal lines and avoid filling up the central screen. On the bottom, a screenshot of *Team Fortress 2* is presented. This game is a multiplayer, first-person shooter game, where players compete as teams toward a specific goal. The game offers players a wide array of possible actions, which additionally change as the game progresses.

to move to state A or B (indicated by different screen background colors), and most often they will end up in the state of their choice—the probability of moving to the undesired state does not change during the experiment and is assumed to be known. In the second step—where participants are now either in state A or state B—they have the choice between two options (A1 vs. A2 when in A or B1 vs. B2 when in B). Each of these options provides rewards with a probability that drifts across time and thus forces participants to continuously update their beliefs about which of these four options (A1, A2, B1, B2) offers the highest reward rate and should therefore be sought.

The ingenuity of this paradigm resides in the fact that it can distinguish two forms of learning: model-free and model based. First, let's suppose that B2 is currently the state with the highest reward rate. Two sequences of actions lead to this state: either A → B2, which is very unlikely, because the probability of ending up in state B after choosing A is very low, or B → B2, which is much more likely to occur. In model-free learning, as in operant conditioning, action sequences that lead to rewards are reinforced, making them more likely to occur in the future. A model-free learner who experiences a big reward for B2, for example, will tend to repeat the same sequence of actions that led to that reward, whatever that sequence was (i.e., A→ B2 or B→ B2). Conceptually, model-free learning is typically associated with habit formation and automatization. In contrast, a model-based learner will use previously acquired knowledge (or a model) to learn and decide what to do next. If that learner experiences a big reward for B2, they will more likely choose B than A on the first step of the next trial, because they know that getting to B increases the chance of getting to B2—even if during that particular trial the learner unintentionally got to B2 after first choosing A. Conceptually, model-based learning is typically associated with goal-directed behavior.

Experimental results show that people rely to a variable extent on both forms of learning and that the reliance on model-based learning correlates positively with cognitive control abilities (Otto, Skatova, Madlon-Kay, & Daw, 2015), working-memory capacity, and being young (Smittenaar, Fitzgerald, Romei, Wright, & Dolan, 2013). Furthermore, model-based learning can be experimentally hindered by increasing working memory load (Otto, Gershman, Markman, & Daw, 2013), stress (Otto, Raio, Chiang, Phelps, & Daw, 2013), or disrupting prefrontal cortex activity using TMS (Smittenaar et al., 2013).

Thus, in addition to stimulating attentional processes, AVGs may encourage players to look for patterns or structure in the game in order to better manage their inherent complexity, and in turn these players may develop the cognitive control abilities necessary to exploit that knowledge.

Game Features That Enhance Control Processes

One of the lessons from the AVG literature, but more generally from the literature on learning and cognitive enhancement, is that control processes, whether attentional or cognitive, play a critical role in fostering broad cognitive enhancements. Over the years, the literature has pointed out two key game features that appear to foster control processes: (1) the need to multitask at all times, calling for graceful recovery from distraction or interruption; and (2) the need to appropriately switch between two main modes of attention, known as distributed and focused attention, as the gameplay unfolds. We briefly review evidence for each of these points.

Most games require that players manage several goals at the same time and continuously decide whether to pursue the ongoing action or switch to different actions. Yet, AVGs weigh heavily on such goal and subgoal management. Some games even have explicit reminders to inform players about a major goal because they can get lost in switching between several subgoals. In games such as *Unreal Tournament*, for example, the player has no choice but to move quickly and unpredictably in space while at the same time avoiding falling out of the arena. While moving, they also have to seek resources (health, weapons), keep track of their enemies, shoot them, and avoid getting shot. This is very different from games such as *Tetris*, where there is only one goal (i.e., to empty the main screen) and one type of action (i.e., place shapes on the board), and although turn-based strategy games also require management of multiple goals, they fundamentally differ in the pace at which those goals need to be evaluated.

The experimental study by Anguera et al. (2013), mentioned already in the section on the zone of proximal development, clearly illustrates the importance of multitasking for cognitive improvements. The authors developed a custom video game called *NeuroRacer*, where older people had to continuously keep a car on a track (i.e., driving) while at the same time monitoring the environment for visual symbols in response to which actions needed to be performed. Older adults who played the multitasking version of the game experienced cognitive improvements in various domains, whereas those who played the same game without multitasking (i.e., performing each of the two tasks in isolation) did not. This result was observed despite all participants being trained at the same level of difficulty. This highlights the importance of scaffolding difficulty load on control processes rather than pure execution speed. In accordance with what we reviewed earlier, the latter is much easier to automatize than the former, most likely accounting for limited cognitive enhancements when execution speed on only one task is trained.

Another cognitive construct associated with broad cognitive enhancements is the ability to flexibly deploy attention both over space and over time as required by the gameplay. The ability to deploy attention over the whole scene, also termed divided attention, is central to all AVGs. Yet, crucially, these games also require that the player constantly switch between focusing on a specific target (e.g., an enemy to be attacked) and at the same time monitoring the periphery for the onset of events that might require a change of plans (e.g., an enemy suddenly appears and attacks the player). Such a switch between two forms of attention is also exemplified in the *Bunnies Are Addicted* *to Carrot Juice* minigame presented in figure 18.2. The requirement to properly allocate divided and focused attention as the video game unfolds provides an extremely potent tool to train what is called *attentional control*, or the flexible allocation of attention over space and time contingent on task needs. Such game features are hypothesized to be central to broad cognitive enhancements and to lead to improved performance on attention tests such as the useful field of view task (UFOV) or the multiple-object tracking task (MOT).

In the useful field of view task, both a central and a peripheral stimulus are flashed on the screen, and participants have to both identify the central stimulus and locate the peripheral one (Yung, Cardoso-Leite, Dale, Bavelier, & Green, 2015). Stimulus presentation times are kept short to avoid eye movements, and the goal is to probe the players' abilities to distribute their attention efficiently in space to process the rapidly presented stimuli. Interestingly, training on the UFOV proper not only improves performance on the task but also has been associated, at least within an older adult population, with more graceful aging, showing surprisingly broad transfer years after the end of training (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Edwards, & Ross, 2007). Today, it is unlikely that the mechanics of the UFOV are rich and varied enough to sustain cognitive enhancements, given the much greater exposure we have to related or similar experiences. Yet, the need to efficiently distribute one's attention over a large scene while at the same time focusing one's attention on minute details remains a basic mechanism to exploit.

The task that arguably best captures changes in attentional control is the multiple-object tracking task (Pylyshyn & Storm, 1988). In this task, a variable number of identical stimuli are presented on the screen. A subset of them are then highlighted as being "targets" before all the items start moving randomly across the screen. Participants' task is to keep track of which items were initially highlighted and are thus targets and which are not. This requires them to distribute their attention across space (on each of the target items) and to dynamically reallocate their attention as these items move in space. A host of studies document enhanced MOT performance among action video game players, as well as after training individuals with action video games.

Interestingly, although the MOT was created for assessment, researchers have started to use it as a cognitive training intervention (Legault, Allard, & Faubert, 2013; Legault & Faubert, 2012; Nyquist, Lappin, Zhang, & Tadin, 2016) and have reported promising results. Nyquist et al. (2016), for example, have used a modified MOT task to train low-vision patients and observed long-lasting improvements in their peripheral vision; training with action video games led to equivalent benefits. Other researchers used the MOT to train attention in younger adults and observed improvements in some aspects of their soccer-playing abilities (Romeas, Guldner, & Faubert, 2016). The effects of MOT training have not been studied as extensively as action video game training. However, we propose that because the MOT, like the UFOV, lacks the rich and complex structures that characterize action video games, it will be less effective at triggering broad cognitive enhancements, especially in young adults at the top of their skills.

A central aspect of action video games is the rich world in which these multitasking and attention-demanding events unfold. Events, whether beneficial (such as encountering a health pack) or dangerous (facing an enemy), may appear unpredictably in time but not completely randomly in location on the screen. Enemies may appear out of windows and doors but generally not suspended in the air or walking through walls. Efficient performance in AVGs involves not only the efficient allocation of attention but also the use of relevant background knowledge to determine where best to direct attention. This is also the case, for example, in the *Bunnies Are Addicted to Carrot Juice* minigame presented in figure 18.2: bunnies come out of the water from anywhere but don't fall from the sky, for example. Furthermore, as the action game player and other game elements move during the game—as in the MOT—the relevant locations on which to direct attention change constantly and thus require that attention be reallocated continuously in coordination with actions from oneself and others. Finally, if an event of interest is detected in the player's periphery, the player has to focus on it; decide whether it is an enemy and, if so, which type of enemy it is (as different enemies may require the use of specific weapons); and decide whether to attack and, if so, actually monitor the consequences of actions to determine whether they are being effective and whether a change of plan is necessary. Thus, in action games, attention is tightly coupled with background knowledge and goals, requiring decision processes over more elaborate and richer representations than in a laboratory attention test. We therefore propose that AVGs are more effective than training interventions focusing on isolated attentional control processes (e.g., using the MOT), because in AVGs attentional control processes need to be implemented and coordinated in the context of rich worlds.

Conclusion

In the previous sections, we discussed several features of action video games that we believe are relevant for effective cognitive training. Our take-home message is that creating effective training interventions is not simply about turning specific dials, such as speed, all the way up. Rather, it is about finding the right combination of parameters. Speed is necessary but not sufficient—it must be coupled with high demands on control processes, for example. Understanding why action video games are effective, then, is more about unveiling a secret recipe than about finding a single magic ingredient. At present, the recipe for effective cognitive training interventions is imprecise. We believe nevertheless that three fundamental principles can be derived from the research on action video gaming reviewed here. First, effective cognitive training programs need to target control processes. Among the most promising candidates, we list increased

Table 18.3

Summary table of the game features hypothesized to promote cognition

General to any well-designed intervention	Zone of proximal development—difficulty scaffolding	*Scaffolding* refers to the incremental difficulty as the player progresses in the game. This scaffolding ensures that players are always challenged and motivated. Adequate scaffolding is a cornerstone of any well-designed intervention. Importantly, to enhance cognition, scaffolding is most efficient if designed to load on attentional and cognitive control processes.
	Rewards and feedback	*Rewards and feedback* are at the core of any learning theory. Reward scheduling and value have been documented since the early days of behaviorism to guide task engagement and learning. Many video games have reward structures similar to that of AVGs, and thus feedback structure, while key for learning, may not be sufficient on its own to trigger cognitive enhancements.
	Information load and variability	*Information load* refers to the amount of information and actions available to the player that need to be taken into account to play. *Variability* refers to the amount of possible variation of these actions and situations that the player can be in. Variability limits automatization of the cognitive processes, thus fostering generalization. While two features are definitely present in AVGs, high information load and variability, they are not exclusive to them and therefore may not be diagnostic of cognitive enhancements training per se.
AVG Specific Feature Combination	Pacing	*Pacing* refers to the temporal pressure put on the player to process information in the service of decision making. While pacing on its own does not guarantee cognitive enhancements, it catalyzes cognitive enhancements when combined with the next two features. Indeed, slow-paced games that require internal models at least as complex as AVGs do not yield the same type of enhancements as AVG play.
	Encourage model-based learning	*Model-based learning* refers to the capacity of the player to extract patterns from the game and form models that can be applicable in various situations, including new situations not previously encountered by the player.
	Game features that load on control processes	AVG play constantly challenges task-switching abilities as well as the capacity to alternate swiftly between a focused and a divided state of attention as the game contingency changes. Keeping such control processes challenged through the learning experience appears critical to inducing broader cognitive enhancements.

Notes: Out of the six features listed, three (difficulty scaffolding, information load/variability, and rewards/feedback) appear common to all video game genres and are likely to be fundamental to any well-designed learning experience. In addition, another three features (pacing, model-based learning, and loading on control processes) appear more specific to the AVG genre. Note that some video games may present one or two "AVG-specific" features, but what is unique to AVGs is their optimization of these three features simultaneously.

attentional resources, more flexible cognitive control, and faster processing speed. Second, effective cognitive training environments should have a structure rich enough to encourage the construction of relevant internal models through model-based learning. These internal models may then apply to new tasks and environments and support learning generalization to new situations. Finally, effective cognitive interventions need to manipulate variability in a way that encourages model-based learning. In that sense, variability does not just mean difficulty adaptation mechanisms. While those are needed to drive learning, other forms of variability (e.g., uncertainty, reward structures, multiple goals, scaffolding, appearance) are necessary to limit full task automatization and encourage the building of rich and diversified internal models.

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19 Games for Workforce Learning and Performance

Ruth Clark and Frank Nguyen

What Are Games For Workforce Learning and Performance?

The goals for workforce learning are somewhat different from those for traditional educational settings. Yes, learning is a major objective. However, the real goal is to help staff perform job tasks in a manner that leads to desired end goals for the sponsoring organization. For example, an intervention for store managers may focus on skills such as financial analysis to define factors leading to sales strength and weaknesses, techniques for providing feedback to staff, optimizing inventory levels, and hiring and training new staff. The interventions may include a pretraining virtual orientation, an ongoing in-store project, classroom training, a profit and loss game, meetings with regional managers, comparing quarterly store data on leaderboards, and training project postings to discussion boards. To achieve organizational goals, interventions often include traditional training—in classrooms (virtual and in person) as well as self-study e-learning tutorials, online performance aids, goal setting, coaching, feedback, leaderboards, and games, to name a few. Unlike in most educational domains, workforce performance interventions aim to help staff achieve targeted knowledge and skill levels in as efficient a manner as possible to minimize the costs of lost production while staff are engaged in instructional events. The efficiency, effectiveness, and learner satisfaction with any performance support intervention are all key metrics in defining how "good" a particular method is at achieving organizational bottom-line metrics.

Let's begin our discussion of games with three examples used in workforce learning. Figure 19.1 is a role-playing game designed to build troubleshooting problem-solving skills. The game is designed for apprentice-level automotive technicians and assigns challenges involving automotive failures that require the learner to select and interpret tests in the virtual shop. At the end of a challenge, the player can see a recap of the tests they performed, view how long each test took to complete, and compare the selections they made with those of an expert troubleshooter. Figure 19.2 shows a game modeled after the commercial game *Concentration*. In this game, the goal is to

Figure 19.1
The *Automotive Troubleshooting Game*.

Figure 19.2
A product features game modeled after *Concentration*.

match product features with different products. The game is designed for sales staff, to build automaticity with new product features when responding to customer questions and requirements. Figure 19.3 shows the *Zombie Game* played by sales associates at a major retail company. In this game, the player has only a few minutes to respond to customer questions or requests or to correct problems such as misplaced products. If the question or problem is not resolved effectively, the customer turns into a zombie.

Well done! One less zombie in the world!

Figure 19.3
The Zombie Game for customer service skills

All customer requests or problems are derived from actual customer feedback. This game has several levels that the player can access from the escalator seen in the back section of the store.

As you can see from these examples, games in workforce learning can have different purposes and quite different features than typical academic games for learning. Many euphoric claims have been made about the power of games for learning. For example, Prensky asserts: “Kids learn more positive, useful things for their future from video games than they learn in school” (Prensky, 2006, p. 4). Before we make claims about games, we need to define the core features of games. Pro and con arguments about games often focus on instructional methods with very different features. In other words, apples are compared to oranges.

Core Features of Games

We will find that to include the diverse array of methods called “games,” we need to identify very general features. The core features of games are:

1. *Interactivity* Games stimulate a high level of engagement, both physical and psychological, in the player. For example, in the *Automotive Troubleshooting Game*, learners

click on various testing tools in the virtual shop (physical engagement) and interpret the resulting data (psychological engagement).

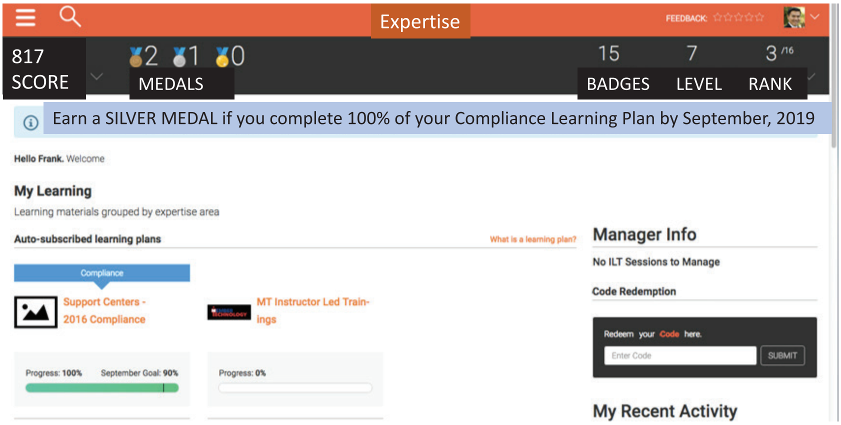
2. *Agreed-upon rules and constraints* Players will share a common understanding regarding legal and illegal moves and consequences of game decisions. For example, in the *Concentration Game*, if two cards do not match, they are turned over for reuse.
3. *Directed toward a clear goal set by a challenge* Game engagement focuses on a challenge that is at the right level—neither too demanding nor too easy. In the *Zombie Game*, the challenges progress in difficulty as the player moves up the escalator to levels with scenarios that are more demanding.
4. *Constant feedback* Feedback in a game can be as simple as hearing a tone, getting points, or seeing a change in the game world. Feedback can also be more extensive—in the form of advice given by an on-screen agent, for example. Further in our chapter, we discuss different forms of feedback that can improve learning from a game.
5. *Alignment with learning objectives or performance goals* The actions, consequences, and feedback of a game should be congruent with learning objectives or desired performance outcomes. For example, the *Automotive Troubleshooting Game* focuses on efficient identification of failures by selecting relevant tests and interpreting the resulting data.

Games versus Gamification

Although these terms lack consistent definitions, for our purposes a game is one form of gamification that meets the criteria just listed. The goal is learning or changes in behavior congruent with organizational goals. Kapp (2012) describes gamification as an approach that "encompasses the idea of adding game elements, game thinking, and game mechanics to learning content" (Kapp, 2012, p. 18). Other forms of gamification involve assigning points or other rewards based on behaviors that are linked to organizational goals. Figure 19.4 is an example of gamification. In this example, a sales associate can see their expertise score derived from a number of performance objectives, various badges or medals earned by learning or sales achievements, and their ranking within their team. Further in the chapter, we review some applications of this form of gamification in a large retail organization.

A Taxonomy of Games

As you can see, the features listed previously incorporate a diverse array of games, ranging from casual games such as *Concentration* to more complex role-playing games such as the *Automotive Troubleshooting Game*. Most trainers are familiar with Bloom's taxonomy and use it to classify objectives and content (Anderson et al., 2001). To identify and plan a game targeted toward learning and performance, a taxonomy of game



Earn a SILVER MEDAL if you complete 100% of your Compliance Learning Plan by September, 2019

Hello Frank. Welcome

My Learning

Learning materials grouped by expertise area

Auto-subscribed learning plans

What is a learning plan?

Progress: **100%** September Goal: **90%**

Progress: **0%**

Manager Info

No ILT Sessions to Manage

Code Redemption

Redeem your Code here.

My Recent Activity

Figure 19.4

Gamification example using a sales associate.

genres is needed. A taxonomy of commercial entertainment video games from the Entertainment Software Association is an example. Table 19.1 summarizes their main game genres, along with percentages of usage in 2016. Would any of these genres apply to workforce learning games?

Strategy games are applicable to any game in which the player or players must make a series of decisions to solve a problem or reach a goal. For example, the *Automotive Troubleshooting Game* awards points for using fewer tests to accurately identify a failure.

Role-playing games are applicable to a challenge in which the player assumes a work role such as a sales associate and responds to clients in ways most likely to lead to a sale or resolve a problem. The *Zombie Game* is one example.

Casual games are quite popular in both the commercial sector and in workforce learning. Often familiar game formats such as *Jeopardy!*, *Concentration*, or *Pop the Bubble* are used as a vehicle for learning factual or conceptual information.

Shooter games can be translated into any game that requires fast and accurate physical responses to a target. These goals are somewhat rare in most workforce learning contexts but may have application to work roles required by transportation safety officials or to quality control inspectors who must scan and identify targets in a limited time. Other obvious applications apply to military and police officer weapons training.

Adventure games involve a fantasy role in a mythical world such as another planet. For reasons we discuss, using a fantasy theme unrelated to the context of the job may not be the best approach for learning in workforce settings. However, adding a fantasy element such as a zombie to a work setting may add a motivational element to play the game.

Table 19.1
A Taxonomy of entertainment games

Genre	Description	Example	Percentage
Strategy	Decision-making skills determine game outcome. Player makes overall decisions.	Chess War games Civilization	36.4%
Role Play	Players take on role of characters who engage in meeting challenges.	MMORPGS (Massively Multiplayer Online Role Play Games) Farmville	18.7%
Casual	Simple rules, short games such as puzzle, cards, quiz show	Jeopardy Board games	25.8%
Shooter	Emphasis on use of weapons such as guns or arrows	Call of Duty Fortnite	6.3%
Adventure	Player assumes a fantasy role in an adventure story.	Myst The Walking Dead	5.9%

From Entertainment Software Association, 2016

Role-playing Games in Workforce Learning

In games such as the *Zombie Game*, the learner plays a role related to their own work assignments—a sales associate in this case. The player is faced with several realistic work problems or challenges to prioritize and resolve in a limited time. Feedback involves changes in the game world (e.g., the customer is pleased, or if problems are not resolved, the customer becomes a zombie). Guidance can be provided in the form of worked examples, feedback, or hints from a coach. Also known as scenario-based e-learning or problem-based learning, role-playing games can accelerate expertise by exposing staff to a number of realistic work scenarios in a compressed period of time. In the *Automotive Troubleshooting Game* (figure 19.1), training time was reduced compared to on-the-job training or hands-on practice in a physical shop. That is because a virtual world can compress time, and lessons learned from the outcomes can be gained quickly. Research studies that we review further in this chapter have shown that role-playing games are motivating and can promote critical thinking skills.

Game Purposes for Workforce Learning

Games for learning can serve one or more purposes as part of a combination of performance support interventions. Typical purposes are summarized in table 19.2. As prework, games are used to introduce basic concepts and guidelines in preparation for a traditional classroom or e-learning course. In some cases, the game is the main vehicle for learning. For example, a game serving as new hire orientation assigns missions to players that require them to identify critical information in virtual corporate locations

Table 19.2

Some common game purposes in workforce learning

Purpose	Description
Pre-Training	The game is used to introduce learners to concepts or principles that will be presented in traditional tutorials.
Initial Learning	The game serves as the main vehicle for learning new knowledge and skills.
Lesson Practice	The game provides the learner with opportunities to apply knowledge and skills presented previously in formal training.
Drill and Practice	Repeated play of a game offers the learner an opportunity to automate knowledge and skills. A language vocabulary game is one example.
Transfer to the Job	The game is designed to be played after formal training as a vehicle to reinforce previously learned skills.
Certification	The game allows professionals who must meet certification or recertification criteria to refresh and review knowledge and skills.

such as human resources, safety manuals, and other places. More often, a game is used to reinforce traditional learning events—sometimes to build skill automaticity through drill and practice. For example, the *Concentration Game* shown in figure 19.2 is scored based on accuracy and response time and is intended to build fluency of responses through repeated play. Many professions require periodic training, often called continuing education or recertification. Games—especially role-playing games—are used for this purpose.

What Do We Know about Games for Workforce Learning and Performance Support?

In spite of considerable enthusiasm at conferences, in books, and on social media, in reality very little is known about the effectiveness or design of games that support adult learning and job performance outcomes. As summarized in table 19.3, in three recent meta-analyses, the vast majority of studies focused on games used at the K–16 educational levels. The Sitzmann (2011) meta-analysis analyzed 65 studies, of which only 7 involved workforce learners. The 58 others involved undergraduate and graduate participants with an overall average age of 25. The Wouters, van Nimwegen, van Oostendorp, and van der Spek (2013; supplemented in Wouters & van Oostendorp, 2013) meta-analysis included 39 studies, among which only 2 involved adult learners. By design, the Clark, Tanner-Smith, and Killingsworth (2016) analysis focused on games for K–16 students. In conclusion, we have very little published academic data on the effects of games on workforce learning or workforce domains such as management, compliance, or sales training.

We report the findings of these meta-analyses, keeping in mind the limitations in the audience and learning domains. All three meta-analyses found game effect sizes

Table 19.3
Meta-analysis data: Games versus traditional instruction

Demographic data	Meta-analysis		
	Sitzmann (2011)	Wouters et al. (2013)	Clark et al. (2016)
Number of studies	65	39	69
Studies with adults	7	2	0
Age of subjects	Average 23	6–25	Average 12
Domains	Not reported	Biology, math, engineering, language	Science, math, literacy, psychology
Effect Sizes	Declarative 0.28 Procedural 0.37	0.29	0.33

around 0.3. In other words, compared to a traditional training lesson, a game resulted in a score three-tenths of a standard deviation better on a posttest. An effect size of 0.3 is considered small. Nevertheless, a 0.3 effect size reported from three different analyses that incorporated around 170 studies suggests that games can teach knowledge and skills as well as if not better than traditional lessons such as PowerPoint presentations, e-learning tutorials, or readings.

Are all games equally effective? Consider an experiment that compared learning from a game intended to teach electromagnetic principles with a slide presentation of the same principles. In figure 19.5, we show a screenshot from the game *Cache 17* (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012).

In the game narrative, players were given a challenge to find lost World War II art in bunkers. To locate the art, players needed to move through bunkers, including opening doors by constructing a wet-cell battery. The instructional explanations shown in the game were duplicated in a slide presentation. Learners were randomly assigned to either play the game or view the slide presentation. The research team reported better learning in less time from the slide presentation than from the game. In this study, a traditional slideshow was more effective and efficient than an interactive game. Not all games are effective as learning tools. What might be some explanations for the lack of results from this game? We consider some moderators reported by the meta-analyses that might help define features or conditions that promote game effectiveness. In this section, we review four elements summarized in table 19.4 that were reported by two or more of three meta-analyses.

1. *Multiple playing sessions are needed.* All three of the analyses found that, to be effective, multiple game-playing sessions are essential. When a game was played only once, it was of minimal learning value compared to traditional instruction: “When only one training session is involved, serious games are not more effective than conventional instructional methods” (Wouters et al., 2013, pp. 256–258). It’s important,

Electrical Connections

Disconnect Copper Material from Door Electrical Panel

Disconnect Aluminum Material from Door Electrical Panel

What is a Wet-Cell Battery?

A wet-cell battery consists of two different metals partially submerged in a chemical solution (such as a **Brine Solution**). The metals are called electrodes, and the solution is called the electrolyte (see diagram below).

HINT: Read about your PDA.

Figure 19.5
Screenshot from *Cache 17*.

Table 19.4
Moderators of game effectiveness reported in meta-analyses

	Effect Sizes		
Moderators	Sitzmann (2011)	Wouters et al. (2013)	Clark et al. (2016)
Multiple game plays	Yes .68 No 0.31	Yes 0.54 No 0.10	Yes 0.44 No 0.08
Game as supplement to other instruction	Yes 0.51 No -0.12	Yes 0.42 No 0.20	Yes 0.36 No 0.32
Visual realism			
- Schematic	Not analyzed	0.46	0.48
- Cartoon		0.20	0.32
- Realistic		0.14	–0.01
Narrative	Not analyzed	Yes 0.25 No 0.45	Thick 0.36 None 0.44

then, that games be sufficiently engaging and relevant to workforce learners to stimulate multiple gameplays.

2. *Schematic or cartoon interfaces are better than photorealistic ones.* Two of the studies evaluated the effects of different levels of graphic fidelity in the game interface. Wouters et al. (2013) and Clark et al. (2016) suggest that simpler visuals, such as schematic or cartoon representations, were more effective for learning than games with highly realistic visuals, including photographs or high-fidelity computer-generated visuals. Mayer concurs, stating: "A straightforward conclusion is that adding realism for its own sake is not a promising game feature, when the goal is to improve learning outcomes" (Mayer, 2019, p. 538). These results may reflect a coherence effect in which simpler visuals have been found generally more effective because they impose less irrelevant cognitive load on learners (Mayer, 2017).
3. *Narratives may decrease learning effects of games.* Two of the meta-analyses found that having little or no narrative was more effective than having a complex evolving story over the course of the game. Clark et al. (2016) conclude: "Results showed that games with no story or thin story depth both had significantly larger effects relative to those with medium story depth" (Clark et al., 2016, p. 25). However, for adult learners, games that involve job-relevant scenarios (also known as scenario-based learning) may be more effective than games lacking work context. As mentioned previously, the research in the meta-analyses had few comparisons involving adult learners playing job-relevant games. However, the evidence on problem-based learning that we review further in this chapter does suggest that job-relevant scenarios may be effective.
4. *Games supplemented with other methods yield more effective outcomes.* All three meta-analyses considered the effects of games as stand-alone instruction compared to games that were supplemented by other instruction. Two of the three reports (Sitzmann, 2011; Wouters et al., 2013) report an advantage for games as a method added to other instructional events. For example, after a tutorial, a game would be used as a practice opportunity. However, Clark et al. (2016) did not find a difference between games used as a supplement to other instruction or as stand-alone learning events.

Let's consider the *Cache 17* game shown in figure 19.5. In this experiment, which compared learning from a game with learning from a slideshow, learners played the game only once. The visuals were of relatively high fidelity, and the game was based on a narrative involving an art discovery mission. In addition, the game was stand-alone, with no additional instruction. All these factors may have decreased the potential effectiveness of the game relative to a slideshow. In fact, Pilegard and Mayer (2016) found better results from this game by adding supplemental instruction in the form of worksheets. We discuss how to make games more effective under value-added research reviewed further in this chapter.

Are Games More Motivating than Traditional Instruction?

Given that multiple gameplays are essential to effective learning, it is important that workforce learners find games sufficiently motivating to stimulate multiple engagements with them. Unfortunately, we lack sufficient data about the motivational effects of games. Sitzmann (2011) did not find sufficient studies to conclude anything about the effects of games on motivation. Wouters, van Nimwegen, van Oostendorp, & van der Spek (2013) reported that, overall, games are not more motivating than the instructional methods used in the comparison groups. They also reported that, for problem solving, games are more motivating than traditional instruction (with average effect size of 0.88). Most studies used a survey to determine learner motivation. For example, Landers and Armstrong (2017) asked undergraduate learners to choose between an instructional scenario involving a serious game and a scenario using traditional PowerPoint instruction. On average, participants anticipated greater value from the game. However, the selection of a game was largest among participants with video game experience and positive attitudes toward game-based learning. The researchers concluded that "individuals with less game experience and poorer attitudes towards games in general may benefit less from gamified instruction than others" (Landers and Armstrong, 2017, p. 506). Clark et al. (2016) did not report motivation measures. Among the different games produced by a large retail organization, the *Zombie Game* was the most popular. Motivation to play was measured by the overall number of gameplays plus the number of repeat plays by the same associate. Perhaps the fantasy element of the zombie plus the scenarios, which were based on actual customer data, served as motivating factors for repeated play. Unfortunately, most research studies lack data on motivation. In addition to learner perceptions, we need measures of how frequently workers voluntarily access and reaccess games.

Competition, Collaboration, and Motivation

The meta-analyses summarized here reported mixed learning outcomes regarding the effectiveness of group versus solo play as well as competition. Wouters et al. (2013) found that learners either playing games solo or playing in a group (usually pairs) had better learning outcomes than learners in traditional instruction, such as a slide presentation or tutorial. Although both solo and group play resulted in better learning compared to traditional instruction, group play was more effective than solo play when compared to traditional lessons, with an effect size of 0.66. In contrast, Clark et al. (2016) reported the best outcomes among individuals playing on their own in a noncompetitive manner. When comparing conditions involving competition, the best results were realized for team competitions compared to individual competitive players. Plass et al. (2013) reported that greater interest and enjoyment resulted from competition and collaboration among middle school students playing a math game. Collaboration in games was associated with stronger intentions to play the game again.

Both collaboration and competition may increase play motivation, although we need more research on the boundary conditions surrounding these features. For example, certain personnel, such as sales associates, may be naturally more competitive and experience behavioral motivation in competitive gamification such as the expertise score and ranking shown in figure 19.4.

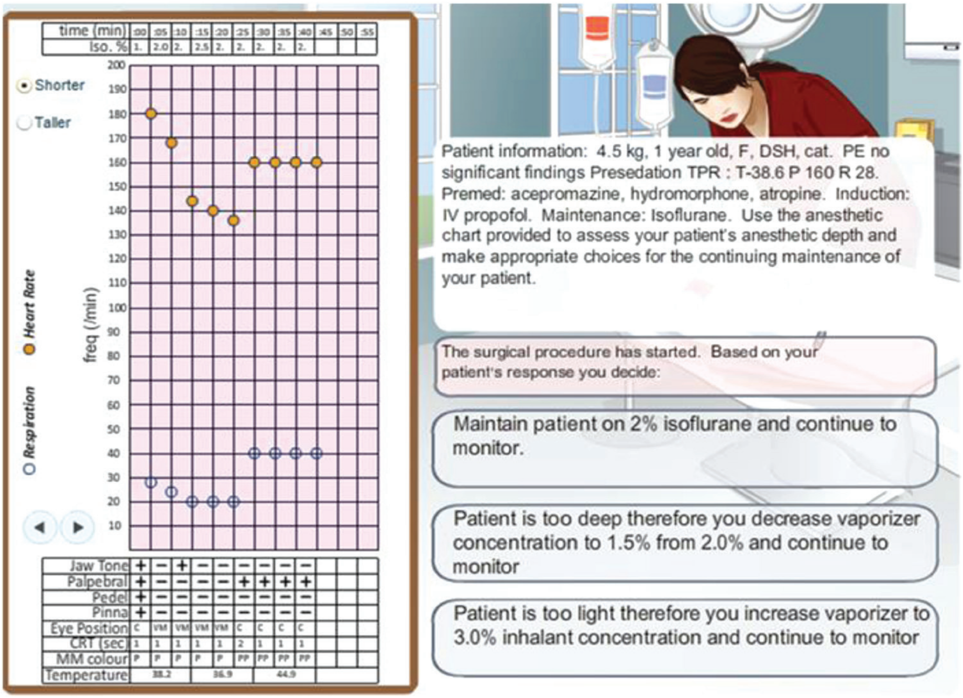
Problem-Based Learning

Consider the example shown in figure 19.6. Designed as training for veterinarians and vet technicians, in this example learners make a series of decisions about animal anesthesia based on physical symptoms, including respiration and heart rate, throughout a surgical procedure. This is an example of problem-based learning (PBL), also called scenario-based learning. While not traditionally considered games, these learning environments include many of the features we listed previously in this chapter as being characteristic of games. For example, most PBL lessons are interactive, goal directed, focus on addressing a work-related challenge or problem, and give feedback (Clark, 2013). Feedback may include changes in the scenario environment, such as the death of the animal if incorrect anesthesia is administered, as well as traditional instructional feedback. Feedback may be given as the learner progresses through the scenario, as in the anesthesia branched scenario example, or at the end, as in the automotive scenario shown in figure 19.1. We classify PBL as a type of role-playing game in which the learner assumes the role of an actor facing a workplace challenge. The *Zombie Game* (figure 19.3) incorporates a number of miniscenarios that the sales associate must address in a limited amount of time. Scores are based not only on the accuracy of the response but also on the priority given to the various challenges offered. For example, resolving a customer issue will generate a larger score than replacing a fallen article of clothing.

Problem-based learning was first introduced into medical education in the 1970s. Rather than classes on science, such as anatomy and physiology, PBL learners are given a patient scenario along with clinical data and learn knowledge and clinical problem-solving skills in the context of the scenario. Historically, PBL has involved a collaborative effort among students, starting with the presentation of the scenario, followed by group discussion to define the problem and identify follow-up resources. Individuals then research the problem and conclude with a group discussion to debrief and resolve the scenario. Problem-based learning is relevant to our discussion because, having been used for over 30 years in allied health education, unlike games for workforce learning, there is considerable research on its effectiveness as well as its motivational potential.

Is PBL More Motivating than Traditional Instruction?

Loyens, Kirschner, and Paas (2012) reported higher graduation and retention rates among students in a PBL program compared to a traditional curriculum. It seems



time (min)	:00	:05	:10	:15	:20	:25	:30	:35	:40	:45	:50	:55
Iso. %	1.	2.0	2.	2.5	2.	2.	2.	2.	2.			

● Shorter
○ Taller

Jaw Tone	+	−	+	−	−	−	−	−	−			
Palpebral	+	−	−	−	−	+	+	+	+			
Pedel	+	−	−	−	−	−	−	−	−			
Pinna	+	−	−	−	−	−	−	−	−			
Eye Position	C	VM	VM	VM	VM	C	C	C	C			
CRT (sec)	1	1	1	1	1	2	1	1	1			
MM colour	P	P	P	P	P	PP	PP	PP	PP			
Temperature	38.2			36.9			44.9					

Patient information: 4.5 kg, 1 year old, F, DSH, cat. PE no significant findings Presedation TPR : T-38.6 P 160 R 28. Premed: acepromazine, hydromorphone, atropine. Induction: IV propofol. Maintenance: Isoflurane. Use the anesthetic chart provided to assess your patient's anesthetic depth and make appropriate choices for the continuing maintenance of your patient.

The surgical procedure has started. Based on your patient's response you decide:

Maintain patient on 2% isoflurane and continue to monitor.

Patient is too deep therefore you decrease vaporizer concentration to 1.5% from 2.0% and continue to monitor

Patient is too light therefore you increase vaporizer to 3.0% inhalant concentration and continue to monitor

Figure 19.6
Example of veterinarian training using problem-based learning.

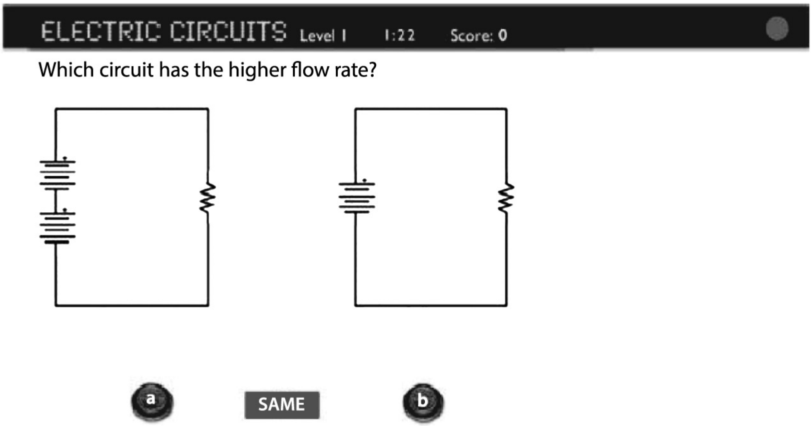
logical that medical students would find learning in the context of a real-world scenario more relevant than learning medical concepts and principles independent of a patient context. One caveat to research findings on PBL is that in many cases the research validity was compromised. In some cases, there was no random assignment. Learners are usually free to select a PBL or traditional curriculum, thus prohibiting random assignment. Eslami, Bassir, and Sadr-Eshkevari (2014) noted that 30% of their studies lacked a control group for some or all measures. As we mentioned previously, the *Zombie Game* was the most popular among the various games offered in this organization, reflecting in part the miniscenarios based on actual customer survey data.

Is PBL Effective for Learning?

Based on data from Dutch medical schools, Schmidt, Muijtjens, Van der Vleuten, and Norman (2012) found medium-level effect sizes favoring PBL curricula. The mean effect size for knowledge was 0.31 and that for diagnostic reasoning 0.51. In a recent review of PBL, Loyens, Remy, and Rikers (2017) summarized a number of studies of PBL drawn from the domains of nursing, chemistry, and Newtonian mechanics, reporting generally positive effects. The authors conclude that, “Given the high number of recent articles investigating the effects of PBL, it can be concluded that PBL is still a popular instructional method in education. Overall, effects seem to be positive” (Loyens et al., 2017, p. 420). Loyens et al. (2017) recommended that research should focus not only on whether a given method such as PBL (or games in the case of this chapter) works but also on the circumstances (e.g., for which outcomes and for which learners they are most appropriate). In other words, research is needed to define the boundary conditions for games and PBL.

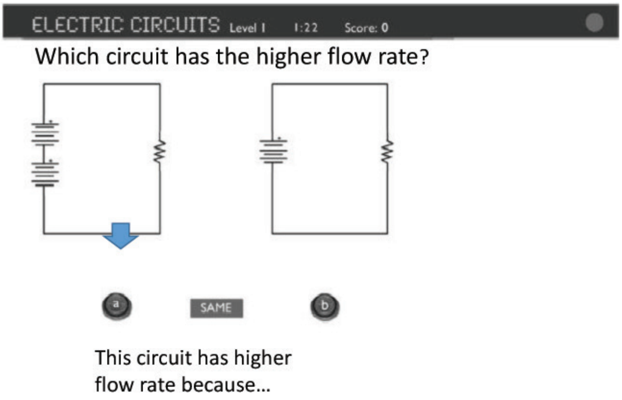
Value-Added Research

There is sufficient data from the research to conclude that games can result in learning equal to or slightly better than traditional instruction. An important follow-up question is, how can we design games to maximize learning and motivation? For example, consider the basic *Circuit Game* in figure 19.7. In this arcade-type game, players learn about electrical circuit flow with various resistances and power sources. In the base version of the game, players select which circuit has the greatest electrical flow. What could be added to this base game to enhance learning? A place to start is to consider what methods have been found to improve learning in traditional e-learning tutorials. Explanatory feedback is one technique that not only informs the learner of the correctness of their response but also provides a short explanation. To determine the effectiveness of explanatory feedback in a game, we would compare learning from the base game shown in figure 19.7 with the same game but with explanatory feedback



Which circuit has the higher flow rate?

Figure 19.7
Basic version of the *Circuit Game*.



Which circuit has the higher flow rate?

This circuit has higher flow rate because...

Figure 19.8
Circuit Game with explanatory feedback added.

added, as shown in figure 19.8. Mayer (2014) refers to research that compares different versions of a game as *value added*.

In value-added experiments, two or more versions of a game are constructed and their learning effectiveness is compared. One version—often called the base game—includes just the essential elements of the game. The enhanced version adds an instructional technique such as feedback or self-explanation questions. Participants are randomly assigned to play the two versions, followed by testing. Mayer (2019) recommends at least five studies showing an effect size of 0.4 or better as the basis for declaring an added method effective.

There are several reviews of value-added methods (Wouter & van Oostendorp, 2013; Mayer, 2014; Mayer, 2019). Table 19.5 summarizes the evidence gathered from value-added research (Mayer, 2019). In this section, we provide a brief summary of value-added methods that meet the suggested criteria.

Present Words as Audio Rather than Text

Evidence has shown that in traditional e-learning tutorials with a graphic component as well as in games, which universally involve a graphical interface, learning is best achieved when words are presented as audio rather than as text (Clark & Mayer, 2016; Mayer 2009, 2014). This is known as the modality principle. For example, in two versions of a botany game called *Design-a-Plant*, Herman the Bug, an on-screen agent, gave explanations in text or presented the same words in audio. Learning was better from the audio version (Moreno & Mayer, 2002). In nine of nine comparisons, the audio version resulted in better learning, with a large effect size, 1.4. The modality principle reflects the dual-channel principle of a limited working memory. While the eyes view

Table 19.5
Value-Added Methods for Computer Games

Method	Recommendation	Number of + outcomes	Effect size
Modality	Present words in brief audio rather than text	9 of 9	1.4
Personalization	Use conversational language including first and second person	8 of 8	1.5
Pretraining	Provide pre-game information regarding content and/or mechanics of the game	7 of 7	0.8
Coaching/feedback	Provide in-game advice and feedback	12 of 15	0.7
Self-explanation	Ask players to select reasons for their responses	13 of 16	0.5

(From Mayer, 2019)

a visual, the words that enter the ears access the auditory centers of working memory and thus maximize its limited capacity.

Use Conversational Language

Research has shown that a personalized approach improves learning from e-learning tutorials (Mayer, Fennell, Farmer, & Campbell, 2004). In a series of experiments, games using conversational language were compared to games that use a more formal tone. Conversational language used first- and second-person constructions such as I, you, and we, and generally projected a more casual vernacular. The advantage of conversational language was seen in eight of eight comparisons and resulted in a large effect size, of 1.5 (Mayer, 2019). Conversational language may promote a social connection between the player and the game, encouraging the player to engage with the game as a social partner.

Provide Game Orientation

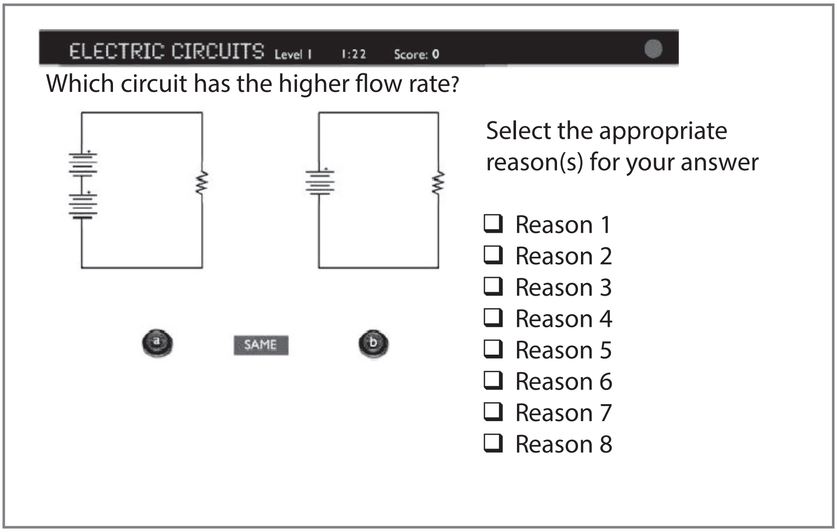
Preclass or prelesson orientations are common methods in conventional training programs. Often called pretraining, these orientations may include a summary of the learning objectives, logistical information, and prework to introduce basic lesson concepts or principles or to initiate an on-the-job project to bring to class. A similar principle applies to games. Prior to starting a game, students may be introduced to learning content such as names and descriptions of concepts and/or a description or demonstration of game mechanics and rules. Mayer (2019) reports that in seven out of seven experiments, providing pregame information resulted in better learning.

Provide Explanatory Feedback and Advice

Evidence has shown that providing feedback that not only tells the learner the correctness of their response but also includes an explanation results in better learning (Moreno, 2004). Similar effects have been found in 12 of 15 games that offered either advice or explanatory feedback. For example, figure 19.8 shows a model of the use of elaborated feedback in the *Circuit Game*. In the base game, feedback consisted only of audio signals and points. In the value-added version, feedback added a verbal explanation.

Prompt Players to Select Explanations for Their Responses

In research on examples in traditional lessons, adding a question that requires the learner to provide or select an explanation for one or more steps of the example has been shown to improve learning from examples (Renkl, 2017). Having to provide or select an explanation forces the learner to carefully review an example that otherwise might be ignored or perused in a cursory fashion. In 13 of 16 experiments, asking learners to select explanations for gameplays resulted in better learning, with an average effect size of 0.5. In figure 19.9, you can see a model for adding self-explanation selection options to the *Circuit Game*. Johnson and Mayer (2010) found better learning from the game with the self-explanation selections than without them. The research reports that self-explanations work more effectively with older students, who are able



Which circuit has the higher flow rate?

Select the appropriate reason(s) for your answer

- ☐ Reason 1
- ☐ Reason 2
- ☐ Reason 3
- ☐ Reason 4
- ☐ Reason 5
- ☐ Reason 6
- ☐ Reason 7
- ☐ Reason 8

Figure 19.9

Model for adding self-explanation selection options to the *Circuit Game*.

to identify reasons for their responses. In addition, asking players to select rather than type in an explanation is more effective. Having to construct and type in an explanation may be too disruptive to the game flow.

Implications for Design of Game-Based Learning for Workforce Learning

Until we have more research involving the effects of games and game features on adult learners and workforce domains, we offer the following recommendations based on the research reviewed here.

1. *Plan a learning context that allows repeated gameplay.* One of the more consistent findings is that games played only once are not more effective than a standard tutorial completed once. A factor to consider is whether multiple plays will be a cost-effective use of a worker's time. If a goal is to reach automaticity—that is, fast and accurate inputs or responses—staff might enjoy multiple practice sessions in a game setting more than traditional drill and practice. Alternatively, if the work context has periods of downtime, short games that are engaging and promote learning might offer a cost-effective learning option.
2. *Keep the graphic interface simple.* It should be less expensive to construct game interfaces that are simple rather than to use high-end photorealistic graphics. If this design recommendation applies to your learning audience, game construction should be easier and less expensive. Until we have additional evidence, stick with schematic or cartoon-type interfaces.
3. *Avoid narratives other than scenarios based on work-relevant tasks.* If designing a role-playing game, create a narrative based on work scenarios. Ideally, you can collect real-world job scenarios that involve decisions shown to promote organizational goals. Base scenarios on customer data, expert stories, or other sources that reflect high-leverage worker actions and decisions.
4. *Integrate games as part of a larger learning or performance support initiative.* Most game reviews reported better learning when the game was a supplement to other training events. For example, a game could offer a practice opportunity immediately after a tutorial or as periodic reinforcement after a tutorial. Alternatively, a game could serve as prework to introduce concepts that will be included in a follow-up tutorial. The main recommendation is to avoid relying on a game as a sole learning resource.
5. *Build value-added methods into your game design.* Evidence from multiple experiments shows that games are more effective when (1) words are presented with audio in a conversational tone using first and second person, (2) learners are oriented toward game content and/or mechanics before starting play, (3) learners receive explanatory feedback and/or advice after responses, and (4) learners select explanations that justify their responses.

Additional research is needed to determine how both learning and motivation may be affected by solo versus group play and by competition either as an individual or as a team. In organizational settings where competition is already instituted, among sales staff for example, a competitive element in games may serve as a motivator.

Gamification and Organizational Improvement

Most corporate human resources departments and training departments recognize that it takes more than a single training event to exert an impact on business objectives. A mixture of formal and informal methods, such as completing e-learning classes, using reference resources, and reading a policy, is needed. One Fortune 500 retail organization gamified worker utilization of learning and performance indicators by creating an expertise score based on tracking of formal and informal learning events in addition to customer feedback, colleague ratings, and other methods. A strong correlation between the expertise score and sales data in an unpublished quasiexperimental study is summarized in figure 19.10. Assigning scores that correlate with expertise can guide organizational decisions that match business needs with individual expertise. For example, a customer

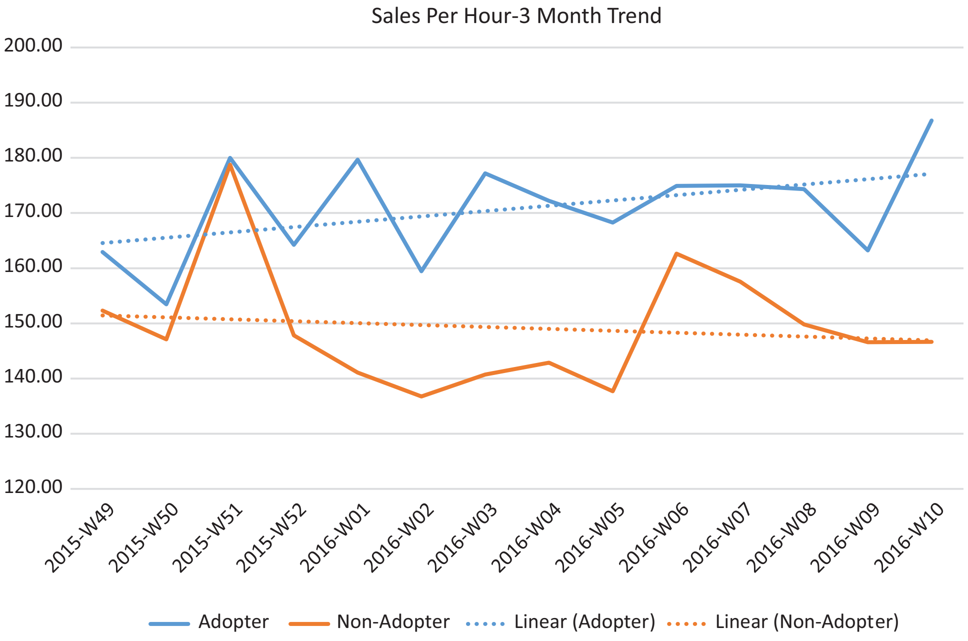


Figure 19.10
Correlation between expertise score and sales data.

inquiry about a particular product line could be routed to individuals with expertise on that product. Alternatively, an analysis of score gaps might indicate targeted hiring or training needs. In short, gamification can provide performance data that inform business decisions and quantify the impact of training and development options that lead to bottom-line business results. Research is needed to identify how different gamification schemes can best be tailored for various workforce domains and staff.

Limitations of Current Research

Very few experiments involve workforce learners or typical training domains, such as customer service, compliance, sales, or organization-specific technical knowledge and skills. It is important to determine which of the findings we summarized in this chapter apply to organizational learning.

Additionally, there is little evidence for the motivational effects of games at any age level. Given that multiple game sessions are recommended to achieve learning benefits, motivation to play is critical. It would be useful to have data not only on student ratings but also on the extent to which learners choose to play a game or replay a game of their own volition. For example, usage tracking found the *Zombie Game* (figure 19.3) to be one of the most popular games included in the organization. Data on factors that make a game appealing and at the same time effective for learning are needed. For example, for which populations might a team competition be more motivating than solo play without competition?

Cost-benefit data are important for those making decisions about workforce learning. What is the cost to construct a game? How long does it take workers to achieve goals with a game compared to a traditional tutorial? In the *Cache 17* game shown in figure 19.5, play took nearly three times longer than viewing a slide presentation, but no learning advantage was obtained (Adams et al., 2012). Organizational decision makers need data on how game design and play compare with traditional tutorial design and completion regarding development time and cost, time for learners to reach the criterion, learner satisfaction, and performance outcomes.

Evidence shows that games are most effective as supplemental events. Data on where in a sequence of training events games can be effectively deployed are needed. For example, are games most useful to support longer-term transfer by periodic play after a formal training event? A framework indicating where games can be productively placed in a learning and performance support progression under different domains and outcomes is needed.

The games used in research vary widely from arcade-type games to role-playing games in the form of workplace challenges. A taxonomy of game types matched to desired outcomes is needed. Design models that specify features for different domains, such as sales or compliance, will help trainers grow beyond games that simply involve answering a question, such as a *Jeopardy!*-type or board game. While these may have their place, fully exploiting the interactive capabilities of technology should make games more appealing and effective.

Research on games in general is in its infancy, and valid evidence on games for workforce learning and performance in particular is practically nonexistent in academic literature. Based on the overall effectiveness of games for learning among college-age students, we believe there is solid potential for games as part of a learning progression. We look forward to evidence that examines how the recommendations in this chapter apply to workforce learning.

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20 Games for Assessment

Valerie J. Shute and Chen Sun

Introduction

The U.S. Department of Education recently blueprinted educational technology (USDOE, 2016). Technology should not only support teaching and learning but should also help to innovate assessment relative to measuring both cognitive (i.e., knowledge and skills) and noncognitive (e.g., affective) outcomes. Our premise in this chapter is that well-designed games—educational and commercial—represent a promising vehicle not only for promoting students' interest and engagement in various fields but also for supporting active learning and assessment of a range of important competencies.

Over the past couple of decades, a wide array of games have emerged to support the development of various competencies, including visuospatial abilities and attention (Green & Bavelier, 2007, 2012; Shute, Ventura, & Ke, 2015), cognitive-shifting skills (Parong et al., 2017), persistence (Ventura, Shute, & Zhao, 2013), creativity (Jackson et al., 2012; Kim & Shute, 2015a), civic engagement (Ferguson & Garza, 2011), and academic content and skills (Coller & Scott, 2009; DeRouin-Jessen, 2008; Dugdale, 1982; Habgood & Ainsworth, 2011; for reviews, see Clark, Tanner-Smith, & Killingsworth, 2016; Tobias & Fletcher, 2011; Wilson et al., 2009; Young et al., 2012). Moreover, game playing is popular across all gender, ethnic, and socioeconomic lines (Entertainment Software Association, 2016). Core game features (e.g., authentic problem solving, adaptive challenges, and ongoing feedback) that are developed in line with various learning theories can engage students affectively, behaviorally, cognitively, and socioculturally (Plass, Homer, & Kinzer, 2015). For example, leveraging constructivism (Piaget, 1973) and situated learning (Lave & Wenger, 1991) can create environments that foster the positive experience of flow (Csikszentmihalyi, 1990) and cultivate mindsets that promote effort-driven, challenge-centered competency development (e.g., Yeager & Dweck, 2012).

Therefore, we focus on game-based assessment (GBA) as a type of assessment where a well-designed digital game serves as the vehicle to measure the degree to which learners are acquiring targeted knowledge and/or skills and support learning processes and outcomes to fulfill educational objectives. But what is GBA? Some researchers operationalize GBA as external assessments (before and after gameplay) to find evidence of learning as a function of playing a game (All, Castellar, & Van Looy, 2016; Clark et al., 2016). Others operationalize it as information captured directly in the game to inform learning (e.g., de Klerk, Veldkamp, & Eggen, 2015; Shute, Wang, Greiff, Zhao, & Moore, 2016). Mislevy et al. (2014) categorized three forms of GBA: (1) student products that are external to the game (e.g., presentations and reports), with raters judging the quality of the products; (2) assessment items that are preprogrammed into games, which may range from simple math problems to complex tasks; and (3) data streams generated throughout gameplay that are used as the basis to identify and score evidence for assessment (e.g., stealth assessment). Stealth assessment refers to evidence-based assessments that are woven directly into the game environment (Shute, 2011). During gameplay, students produce rich sequences of actions while performing complex tasks, drawing on the very competencies that we want to assess. Evidence needed to assess the skills is thus provided by the players' interactions with the game itself (i.e., the processes of play, captured in the log files). Stealth assessment uses evidence-centered design (Mislevy, Steinberg, & Almond, 2003) to create relevant conceptual and computational models that are seamlessly embedded into the game so that knowledge and/or skills can be assessed without being noticed by students (Shute & Ventura, 2013). The term stealth assessment and its technologies are not intended to convey any type of deception but rather reflect the invisible capture of gameplay data, and the subsequent formative use of the information to help learners (and, ideally, help learners to help themselves).

In both formal (e.g., school classroom) and informal (e.g., afterschool programs) settings, the games that we focus on in this chapter are interactive, digital games that support learning and/or skill acquisition (Shute, 2011). According to Facer (2003), good games are engaging. They promote full absorption within an activity by using age-appropriate challenges and intrinsically motivating objectives. Assessment within such games not only requires data collection and analysis but may also include meaningful data interpretation, along with consequential actions taken based on the interpretation to achieve learning objectives (Shute & Ventura, 2013).

Because this type of GBA is based on gameplay performance, students' interactions with games are recorded as interrelated data points, each of which provides specific evidence for learning (DiCerbo, Shute, & Kim, 2017; Levy, 2014; Shute, Ventura, Bauer, & Zapata-Rivera, 2009). Also, GBA provides ongoing assessment based on a continuous stream of data rather than discrete data characterized by standardized tests. As a result, with GBA, educators can monitor students' learning progression over time (Shute, Leighton, Jang, & Chu, 2016). Furthermore, because the assessment is embedded deeply in games, students do not notice they are being assessed (Delacruz, Chung, & Baker, 2010; Shute, 2011). Thus, GBA can be used to assess what cannot be easily measured via short, summative paper-and-pencil tests and can save time that would normally be used to administer and score tests—so that more time may be devoted to improving learning (Shute, Leighton, et al., 2016). Finally, GBA can be used formatively not just to measure learning but also to support it (Delacruz et al., 2010; Shute, Leighton, et al., 2016).

In the following section, we review the literature on game-based assessment and then provide an example of GBA using the game *Plants vs. Zombies 2* (Electronic Arts, 2013).

Literature Review

GBA, as defined in this chapter, has formative functionality (i.e., it is used for assessing and supporting learning). The rise of such assessments is credited to advances in technologies, the learning sciences, and measurement methodologies (Leighton & Chu, 2016; Shute, Leighton, et al., 2016; Timmis, Broadfoot, Sutherland, & Oldfield, 2016). In addition, because games are intended to be engaging, they provide rich and interesting environments for students to experience and/or explore (Clarke-Midura & Dede, 2010; Gee, 2005), in contrast to typical assessments.

How can we accurately assess students' evolving knowledge, skills, and other attributes via gameplay? Assessing students' interactions with a game requires the use of a principled assessment design framework. There are several major frameworks from which to choose (see Shute, Leighton, et al., 2016). In addition to establishing the infrastructure of the assessment (e.g., competency, evidence, task, and assembly models), designers and researchers need to ensure the psychometric quality of the assessment relative to reliability, validity, and fairness (DiCerbo et al., 2017; Mislevy et al., 2014).

The most commonly used assessment design framework that is applicable to and suitable for GBA is evidence-centered design (ECD) (Mislevy et al., 2003). In a nutshell, ECD frames how to design assessments that can elicit valid evidence to support intended claims. It guides designers to specify targeted competencies, observables that can reveal competencies, and tasks with which students interact. ECD is particularly suitable for GBA design. First, data generated via gameplay are usually multivariate (de Klerk et al., 2015; Levy, 2013). By establishing multivariate competencies in the competency model (i.e., the unobservable or latent variables), researchers can determine the associated behavioral evidence (i.e., the observable variables) and specify the task features to elicit those behaviors, along with values assigned to those behaviors (Mislevy et al., 2003). To extract relevant data from gameplay, it is important to identify relevant types of student-task interactions that provide explicit links between behaviors and competencies; decide on the granularity of the observables to be collected; and choose the appropriate statistical model for accumulating and interpreting evidence (Levy, 2013).

Choosing the right statistical model relates to the second advantage of using ECD; that is, drawing valid inferences of students' competency states. The most frequently used statistical model in the ECD framework is the Bayesian network (BN) (de Klerk et al., 2015; Mislevy et al., 2014), where a BN is a probabilistic graphical model that represents a set of random variables and their conditional dependencies via a directed acyclic graph. BNs generate conditional probabilities of students' competencies with graphical representation of the statistical relationship(s) between the targeted competency variables and associated indicators. Additionally, BNs update beliefs about students' competencies dynamically (Mislevy et al., 2014), so that ECD can produce real-time data across time, enabling profiles of learning progression (Shute, 2011; Shute, Leighton, et al., 2016).

Some examples of GBA for cognitive skills using an ECD framework include the measurement of scientific inquiry skills (Baker, Clarke-Midura, & Ocumpaugh, 2016; Clarke-Midura & Dede, 2010), systems thinking skills (Shute, Masduki, & Donmez, 2010), creativity (Kim & Shute, 2015a), and problem-solving skills (Shute, Wang, et al., 2016). Additionally, GBA using ECD is well suited to assess content knowledge in various domains, such as mathematics (Delacruz et al., 2010), urban planning (Rupp, Gushta, Mislevy, & Shaffer, 2010), physics (Shute, Ventura, & Kim, 2013), and biology (Conrad, Clarke-Midura, & Klopfer, 2014; Wang, 2008). It is worth noting that Conrad, Clarke-Midura, and Klopfer (2014) developed a modified version of ECD (i.e., experiment-centered design, or XCD) in an online game, specifically for students to conduct scientific experiments to answer questions and input answers, in either open-ended or closed-ended contexts.

Leighton and Chu (2016) similarly envisioned a new design framework that integrated ECD with the cognitive diagnostic assessment system (CDA) (Embretson, 1998) to offset each other's shortcomings. CDA is a framework that focuses on measuring students' cognitive abilities via items that have been designed to measure, based on theories and models of cognition, specific knowledge structures and processing skills in students to provide information about their cognitive strengths and areas for improvement (Leighton & Chu, 2016). The authors discussed the similarities, differences, and challenges of the two design frameworks. They concluded that the new combined framework—in the hands of learning scientists and subject matter experts—could help identify the most relevant information as evidence and establish a widely applicable, socioemotional-cognitive assessment model.

In addition to existing assessment design frameworks, there are some homemade frameworks that target a specific game type and/or domain. For instance, Nelson, Erlandson, and Denham's (2011) framework was designed for the genre of massively multiplayer online virtual games. They identified three primary sources for data extraction: (1) players' location and movement patterns in the game; (2) interactions with various objects; and (3) the type, content, and purpose of communication activities.

They illustrated how to utilize each data source using various virtual games as examples regarding the kinds of behavioral data to look for and how to interpret the data. Also, they stressed that game-player interactions normally involve at least two of the three sources. Thus, tracking and analyzing data from different sources simultaneously and continuously can enable timely feedback during gameplay as well as post hoc analyses.

Another framework for 3-D GBA has been used in the military. Koenig, Lee, Iseli, and Wainess (2010) used a framework that includes ontology creation and Bayesian networks. Ontology creation involves defining the domain in terms of its elements and relationship(s) between and within elements. BNs are employed to model the relationships. Koenig et al. tested their framework within a firefighting game consisting of 10 scenarios. After comparing the in-game estimates with human ratings for each scenario, the researchers reported that the estimates derived from the BNs diverged from expert ratings in several scenarios, but on average the agreement appeared to be reasonable—at around 58%. They attributed the divergence to either the quality or robustness of the BNs or to inconsistencies in human ratings over time. The next section examines general properties of GBA (e.g., validity, learning support, and factors influencing GBA quality).

Validity of Game-Based Assessment

As with the design and development of any assessment, it is necessary to validate GBA. To accomplish this, some researchers have examined the correlation between in-game measures and external measures, while others have converted existing summative tests to GBA.

Correlation between in-game and external measures In a study using *Physics Playground* to measure and support physics understanding, Shute et al. (2013) reported significant correlations between the in-game measures related to learning physics (e.g., number of gold and silver trophies obtained, time on task) and external learning outcome scores on a qualitative physics test, suggesting convergent validity. Similarly, Delacruz et al. (2010) examined the validity of a puzzle game to teach and assess math. They showed that the math pretest scores predicted game scores, which in turn predicted math posttest scores (controlling for pretest score). In another study examining the development of math abilities using GBA, Roberts, Chung, and Parks (2016) designed a website containing a series of math games for children. The website employs learning analytics to track indicators such as correctness of responses while children are playing the games. Learning analytics are intended to gather, measure, analyze, and report data generated by learners to understand and improve learning and associated contexts (SoLAR, 1st International Conference on Learning Analytics and Knowledge, 2011, cited in Siemes, 2013). The in-game analytics significantly correlated with scores from a standardized math test. Finally, using a game to teach middle school students evolution, researchers reported that certain in-game behaviors (i.e., number of times and duration viewing relevant information, number of avatars used, and number of rounds played) correlated with game scores (Cheng, Lin, & She, 2015). Moreover, game scores and posttest scores were significantly correlated.

In addition to subject matter content, researchers have tested GBA validity in relation to other student skills and attributes. For instance, persistence was measured in *Physics Playground* based on indicators, such as the average time spent on unsolved problems and number of revisits to work on an unsolved problem (Ventura & Shute, 2013). The in-game measures, in turn, were significantly correlated with an external measure of persistence (i.e., performance-based measure; see Ventura et al., 2013) as well as with scores on a physics posttest. Along the same lines, DiCerbo (2014) modeled persistence relative to two in-game indicators—total time on game quests and number of quests completed. Confirmatory factor analysis showed a good model fit, where the indicators explained a significant portion of the variance, with a reliability of .87. In another study, Shute, Wang, Greiff, Zhao, and Moore (2016) embedded a stealth assessment of problem-solving skills in the game *Plants vs. Zombies 2*. The in-game measures of problem-solving skills significantly correlated with two external measures of problem solving, MicroDYN (Wüstenberg, Greiff, & Funke, 2012) and Raven's Progressive Matrices (Raven, 1941).

In conclusion, validating GBA with external measures entails two prerequisites: (1) careful selection of in-game indicators for targeted knowledge and/or skills and (2) use of a well-established (i.e., valid and reliable) external measure of the same construct.

Mapping game-based assessment to summative, performance-based assessment An alternative approach to establishing the validity of GBA involves mapping GBA to a summative, performance-based assessment. Two recent studies of this type were conducted, both within a vocational education setting. In one study, the original performance-based test required assessors to assume different roles (e.g., clients), to interact with students, and then to judge their qualifications to be an information technology communication manager (Hummel, Brinke, Nadolski, & Baartman, 2016). To ensure the content validity of the GBA, the researchers employed the following four steps: (1) identify relevant performance indicators that can be elicited by gameplay; (2) design game tasks; (3) develop instructions for GBA users; and (4) evaluate whether the game tasks map to the performance metrics that were the target of the original assessment. After implementing the GBA and interviewing assessment experts, the researchers reported that GBA could fully assess 20 out of 32 performance indicators and partly assess 5 more indicators, while the rest of the indicators could be assessed face-to-face. The GBA's main advantage is that it avoids inconsistencies and biases that are frequently present in human ratings. Moreover, it saves time in assessment execution and documentation of results.

A second study developed an interactive virtual assessment that had been mapped to real-life performance-based test scenarios (de Klerk, Eggen, and Veldkamp, 2016).

The real-life test measured students' abilities to inspect the working conditions and procedures within a confined space and then respond properly to emergencies. As with the previous example, the authors first defined performance indicators in the virtual environment. Then, experts rated each indicator in terms of its difficulty and evidentiary weight relative to associated knowledge and skills. Based on experts' ratings, the authors constructed two scoring models for assigning values to the indicators and then transforming the scores to BNs. Finally, they compared the scores generated by the two scoring models with those on a real-life performance-based test. The results indicated that one model estimated students' qualifications more accurately than the other.

Such mapping methods are relatively scarce. Further studies are needed to provide evidence for their reliability and validity. One question to consider is whether the GBA can be consistently and accurately mapped to the original performance-based assessment. The other question is whether such a mapped GBA can eventually gain recognition and replace the original assessment to serve a high-stakes, summative purpose. Currently, GBA typically serves a formative function, to support learning processes and outcomes, described next.

Game-Based Assessment to Support Learning

Well-designed GBA can support some degree of learning without explicit instructional support (see Shute et al., 2013). As mentioned earlier, middle school students played *Physics Playground* for about three hours (across three days) and also completed pretests and posttests on qualitative physics. The students' in-game performance was assessed via a range of indicators, such as number of solution attempts, time per level, and level of trophy obtained. The results showed small but significant learning gains in physics understanding, measured by pretests and posttests, and in-game measures were significantly correlated with test scores. Moreover, both male and female students significantly improved their physics knowledge as a result of gameplay. Although the males' incoming knowledge was slightly higher than the females', their posttest scores were comparable. The researchers concluded that this GBA is fair to use for both male and female students, and, in the future, feedback (e.g., explanations and visualizations) can be integrated into the game to facilitate deep learning.

Game-based assessment also can be leveraged to provide various forms of feedback to support learning. To illustrate, a GBA was designed using ECD to measure knowledge related to geology and space science (see Reese, Tabachnick, & Kosko, 2015). The GBA tallied learners' progression toward the learning goals every ten seconds. The data were stored in a database and thereby served as the basis for timely feedback. The feedback (e.g., on-screen scaffolding messages and player dashboards) was integrated directly into the game to facilitate goal achievement. For instance, current point tallies were displayed at all times, and the scaffolding assumed various forms, such as text, pictures, and animations. Scaffolding was presented when learners repeatedly made mistakes. Based on the data, the researchers calculated the rate of learning four topics (i.e., mass, heat, radiation, and density) in two samples for generalizability. The results showed that the two samples progressed at similar rates in learning mass, heat, and radiation but differed relative to learning density. Generally, the learning rates for both samples were significantly greater than zero, providing evidence that GBA can facilitate learning.

Arnab et al. (2015) utilized learning analytics in a game to assess and support knowledge of first aid techniques among college students. For the in-game measures, students needed to select their answers (i.e., reactions to different scenarios) from several pictorial choices. Whatever choices the students made, correct or incorrect, the associated consequences of the selected action would show up immediately as feedback. In addition, pretests and posttests were implemented to assess students' knowledge gains. The results showed that the in-game scores predicted posttest scores, and there were significant learning gains. The researchers recommended future research to use in-game measures to predict students' performance and offer personalized support based on the in-game estimates.

Other researchers have compared two versions of the same game (e.g., feedback present vs. feedback absent) to test whether the GBA with embedded feedback is a better design to improve learning compared with GBA without feedback. In one such comparison study, Huang, Huang, and Wu (2014) designed two versions of a math game where second-grade students answered math questions related to buying various goods. One version provided timely feedback (i.e., hints or explicit feedback) when errors occurred, while the other version did not. The results showed that the students who played the game with diagnostic feedback produced significantly higher posttest scores than those who did not receive feedback. The authors concluded that the diagnostic feedback helped students learn from their errors by providing instructional support according to the types of mistakes they made.

Tsai, Tsai, and Lin (2015) similarly investigated the effects of the GBA with immediate elaborated feedback compared to the version with only verification feedback on supporting middle school students' acquisition of energy knowledge. The GBA for energy knowledge assumed the form of a tic-tac-toe game where students needed to answer questions. The GBA placed a tick mark when the answer was correct or a cross when the answer was incorrect. In the elaborated feedback condition, immediate explanations of answers to questions were provided on-screen for students' reference, in addition to the verification feedback (i.e., tick marks and crosses). The researchers found that only the game with elaborated feedback significantly improved knowledge acquisition from pretest to posttest, supporting other studies' findings that GBA with timely and explanatory feedback facilitates learning.

Examining the effects of three types of formative assessments on learning, Wang (2008) conducted a study with fifth graders in a two-week biology course. Six classes were randomly assigned to one of the three conditions that used different types of formative assessment to support learning. In addition, Wang administered a pretest and posttest on biology knowledge and used different test items for summative and formative assessments.

The first type of formative assessment was a paper-and-pencil test administered at the end of each class, with correct answers given to students as feedback. The second type of assessment was a web-based test, where students received immediate feedback concerning the correct answer for each of their incorrect responses. The third type was a GBA (i.e., an online multiple-choice quiz game), where students could press certain buttons to receive a hint (e.g., to see others' choices, such as "80% of test-takers chose A as the correct answer"). However, use of the hint function was limited to prevent its overuse. Using the pretest as a covariate, findings showed that the three types of formative assessments significantly influenced posttest scores. Post hoc analysis showed that posttest scores in the GBA condition were significantly higher than in the two other conditions. Wang contended that students were motivated by the gamelike quiz and tended to actively refer to resources (e.g., learning materials or asking for clarifications from teachers).

Game-Based Assessment to Model Factors Influencing Learning

In addition to its ability to support learning, GBA can also be used to identify particular factors and patterns that contribute to successful learning. For example, several researchers have recently examined the behavioral patterns related to science learning (Baker et al., 2016). They analyzed scientific inquiry behaviors among middle school students via a virtual environment that provided various science-related scenarios for students to solve. Focusing on students' final answers as well as the procedures they used to conduct scientific tests, the researchers used confirmatory factor analysis to identify 29 behavioral patterns for successful learning that could be generalized across scenarios. In short, students' final correct answers were predicted by time spent on an information page and the frequency of visits to it. The indicators related to successfully identifying causal relationships included obtaining necessary items for conducting experiments (e.g., water or blood samples), visiting the virtual science lab frequently, and running relevant tests (e.g., blood or DNA tests).

Cognitive and noncognitive variables and their relationships to learning were examined and modeled in a study conducted by Shute et al. (2015). The researchers gathered data from middle school students playing *Physics Playground* and additionally collected data on students' persistence, incoming physics knowledge, in-game performance (e.g., time on levels, successful and unsuccessful solutions, trophies received), affective states, and physics posttest scores. They used structural equation modeling to construct various models to interpret the relationship between learning outcomes and the other variables. The final model demonstrated that pretest scores were significantly related to engagement, in-game performance, and posttest scores. Also, engagement and frustration were two mediating variables between pretest and in-game performance, suggesting the importance of creating adaptive tasks that exceed students' current proficiency level by just a little. Furthermore, in-game performance significantly influenced posttest scores. The results of the relationships among the different variables pertaining to learning provide implications for instructional support.

Factors Influencing the Quality of Game-Based Assessment

The quality of GBA depends on its underlying framework (e.g., ECD) and its psychometric properties (e.g., reliability and validity), as mentioned at the beginning of this review. To date, a few attempts have been made to explore the factors that affect GBA quality. For instance, changing task variables can affect the psychometric quality of GBA tasks (Almond, Kim, Velasquez, & Shute, 2014). Tasks possess particular features that govern their presentation as well as the associated work product. These features can affect how learners respond to a task and the evidentiary weight of the responses. For example, consider a math test on addition and subtraction. The format of the test (e.g., multiple-choice or word problem) influences how much information you would get from students' responses (e.g., correctness of the choice selected or the whole problem-solving process). In addition, the format may have some unexpected confounds—such as reading ability serving as a potential confound in the solution of math word problems. There are many other variables to consider in designing assessment tasks and before implementing them, such as how to design two different tasks that are of the same difficulty and how to make sure about 50% of test takers can complete the task correctly. Task variables help researchers and/or designers determine task variants, difficulty, and discrimination; thus, interactions between learners and GBA tasks can yield valid evidence to measure targeted competencies.

Kim and Shute (2015b) examined how game design features (i.e., linearity vs. nonlinearity) affect the psychometric properties of the stealth assessment embedded in *Physics Playground*. Linearity refers to unlocking game levels, whereas nonlinear games offer learners control of the levels they choose to play. In this study, undergraduates in both linear and nonlinear conditions were instructed to obtain as many points as possible (and were also informed that they can score higher by earning gold trophies for elegant or efficient solutions, which count as double the score of silver trophies). To determine validity, the researchers tested the evidentiary weight of in-game indicators on physics understanding in the two conditions. The evidentiary weight of silver trophies significantly differed between linear and nonlinear conditions. Posttest scores significantly correlated with silver trophies in the linear condition but with gold trophies in the nonlinear condition. The change in validity might be because linearity did not motivate learners to explore the most efficient solution (i.e., gain gold trophies) to the various physics problems but instead just to unlock as many levels as possible by gaining silver trophies. Consequently, only students in the nonlinear condition who aimed for optimal solutions significantly improved their physics learning. To test reliability, the researchers used confirmatory factor analysis to construct the best-fitting model for both conditions. The calculated reliability coefficients are .96 and .92 for the linear and nonlinear conditions, respectively, and the two coefficients are comparable to each other. Thus, reliability of the GBA was not affected by whether the game was linear or nonlinear.

Finally, a recent white paper by Mislevy et al. (2014) describes the factors influencing the psychometric qualities of GBA designed with ECD. The researchers argued that high-quality GBA can serve various purposes (i.e., formative, summative, and even large-scale high stakes) as well as provide valuable information about learning for students, teachers, and designers. They used a game called *SimCityEDU*, created by Glass Lab and its partners, as a running example to show how to ensure the reliability and validity of a GBA. The area of psychometrics concerns the observable evidence that can be identified and extracted from a given work product (i.e., the log file data in this case) to assess unobservable competencies. The most influential psychometric factors related to GBA involve identifying relevant evidence and selecting measurement models to trace and process the gaming/learning data. Researchers and designers should additionally consider how to interpret the evidence derived from particular gaming situations, design adaptive games to provide optimal learning experiences, and analyze data related to collaborative activities. Mislevy et al. (2014) introduced a new framework for this called evidence-centered game design (ECgD), which involved defining targeted real-world competencies, aligning game-world competencies with the real-world ones, integrating formative feedback systems into the games unobtrusively, and engaging in iterative design processes to create engaging games with embedded assessment to support deep learning. In the next section, we illustrate the application of a specific type of GBA—stealth assessment in *Plants vs. Zombies 2*, to measure students' problem-solving skills (Shute, Wang, et al., 2016).

Example of a Game-Based Assessment

Plants vs. Zombies 2 is a widely popular 2-D game that requires players to strategically guard their houses against zombie invasion. Players manipulate various plants in the battlefield (i.e., the chessboard-like lawn in front of the house) to either attack zombies directly or slow them down. When selecting and placing their plants, players need to collect falling suns to earn energy points. *Plants vs. Zombies 2* is an appropriate vehicle in which to embed a stealth assessment measuring problem-solving skills. Again, stealth assessment is defined as an evidence-based assessment woven directly and invisibly into the fabric of the learning or gaming environment (Shute & Ventura, 2013) to measure and support learning. The models undergirding stealth assessment are created using ECD. The combination of ECD and stealth assessment makes it possible to build evidentiary arguments about students' competency levels via three key models—competency model, evidence model, and task model.

The competency model includes claims about competencies (i.e., unobservable variables) to be assessed. The evidence model specifies behavioral evidence (i.e., observable variables) that can be collected and analyzed or scored to support the claims made in the competency model. The evidence model also quantifies the observables by establishing scoring systems to align evidence with claims statistically. For instance, an observable can be indicated as a ratio to represent various levels of a competency, such as "poor" (0–0.25), "okay" (0.26–0.50), "good" (0.51–0.75), and "very good" (0.76–1). Stealth assessment typically employs Bayesian networks (BNs) to establish statistical relationships among the indicators and the competency variables. The task model provides templates for the design of tasks that can elicit targeted evidence. Note that when using an existing game with its existing levels, the task model specification isn't needed.

To design the stealth assessment in *Plants vs. Zombies 2*, Shute et al. (2016) first constructed a competency model of problem-solving skills based on an extensive literature review. The overarching competency of problem-solving skill involves four facets: (1) analyzing givens and constraints of the problem; (2) planning a solution pathway; (3) using tools and resources effectively and efficiently; and (4) monitoring and evaluating progress. Next, the researchers identified in-game indicators (i.e., the observables) associated with each competency variable (i.e., the unobservables) and then assigned values to indicators to reflect the quality of students' performance. For instance, consider the problem-solving facet of "using tools and resources effectively and efficiently." One of the plants in the game is iceberg lettuce, and its function is defensive—to temporarily freeze zombies. Another plant in the game is the snapdragon. Its function is offensive, attacking zombies by breathing fire and burning them. If a player plants iceberg lettuce within a snapdragon's fire range, its freezing effects will be canceled by the fire. Thus, one indicator (of many) related to using tools effectively is whether the student planted an iceberg lettuce near a snapdragon (i.e., within a 3×3 space; see figure 20.1). This indicator was scored by calculating the ratio of iceberg lettuces planted near snapdragons divided by the total number of iceberg lettuces planted. In this case, the higher the ratio, the lower the associated competency level would be. There are four equally divided ratio intervals: very good (0–0.25), good (0.26–0.5), okay (0.51–0.75), and poor (0.76–1).

After establishing the scoring system across all the indicators per facet, the researchers constructed BNs to represent the statistical relationships between indicators and relevant competency variables for each game level. Individual BNs were constructed for each level because each level varies in terms of its difficulty, discrimination, relevant indicators, and competency variables. The prior probabilities of problem solving

Figure 20.1
Using iceberg lettuce ineffectively in *Plants vs. Zombies 2*.

problem for each student is the same—that is, there is an equal likelihood of being high (33.3%), medium (33.3%), and low (33.3%) (figure 20.2). Then, as data are generated by students during gameplay, these probabilities quickly and repeatedly change. Ongoing data (from the indicators) are input to the BNs, and the BNs process the data and update the competency estimates. The estimates will approach a student's true competency level with the influx of gameplay data because BNs dynamically adjust estimates according to the student's real-time performance.

Figure 20.3 shows an updated BN, where the player demonstrates poor iceberg lettuce use (shown in node I37). The updated result means there is about a 50% chance that the problem-solving skill of this player is low.

In addition to ensuring the internal validity of the stealth assessment, the researchers carefully selected two external measures related to problem-solving skills (specifically in terms of rule identification and rule application) to test its external validity. Raven's progressive matrices (Raven, 1941) require students to infer rules from given matrices to fill in one missing piece of information. MicroDYN (Wüstenberg et al., 2012) requires that students recognize relationships among variables and then apply these rules to achieve the desired results. The results from a study conducted with about 50 middle school students playing the game and completing the two external

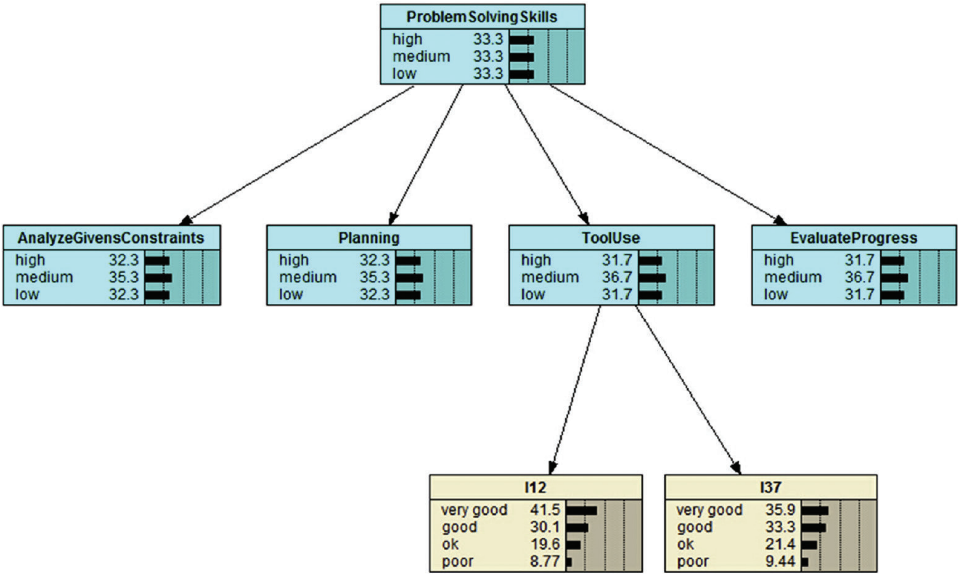

Figure 20.2

BN example of prior probabilities (adapted from Wang, Shute, & Moore, 2015).

measures across three days showed that the stealth assessment estimates of problem-solving skill from the game significantly correlated with the two external measures, suggesting construct validity.

The example illustrates the validity of stealth assessment as GBA. The strength of stealth assessment lies in the following: (a) the competency model is built on a conceptual foundation (i.e., resulting from a comprehensive review of the construct in question); (b) the evidence model establishes specific rubrics for scoring in-game performances as well as statistical relationships between the evidence/indicators and what is being assessed; (c) the assessment is seamlessly and directly embedded into the game, resulting in the merger of learning and assessment; (d) learning can be supported by providing timely feedback—at various times and grain sizes; and (e) it is able to concurrently assess multidimensional competencies. Next, we discuss the theoretical and practical implications and limitations of GBA.

Theoretical Implications

This chapter highlights the potential of GBA to measure and support learning simultaneously. Students' learning can be monitored continuously, without disrupting learning processes (DiCerbo et al., 2017; Shute, Leighton, et al., 2016). In addition to

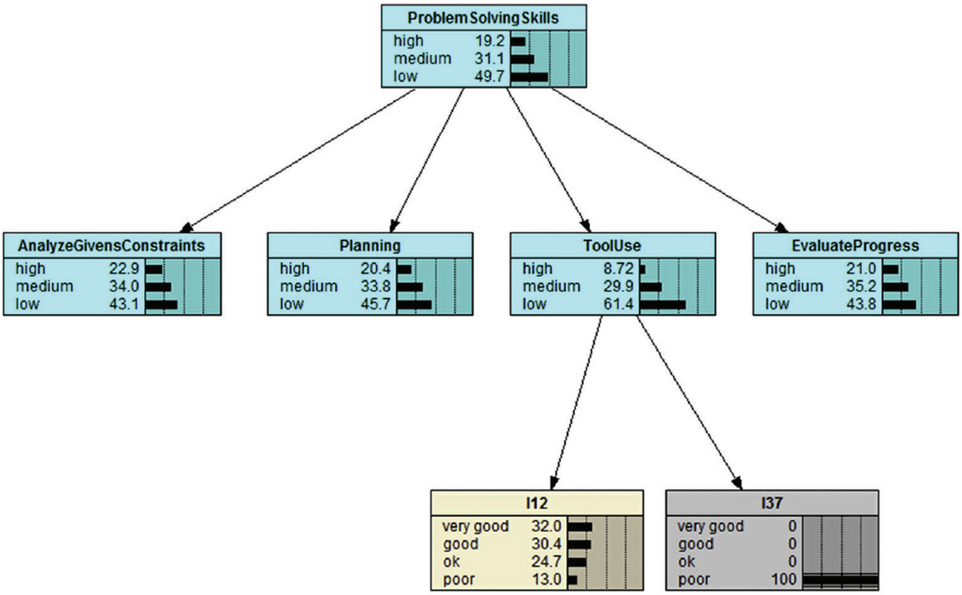

Figure 20.3

An updated BN after receiving evidence (adapted from Wang, Shute, & Moore, 2015).

content knowledge, GBA is well suited to assessing complex skills (e.g., problem solving and creativity) that are normally difficult to assess with traditional measures (Clarke-Midura & Dede, 2010; Timmis et al., 2016). GBA allows the assessment mechanism to be built directly into the game, comprising an integrated design for games and assessment. Researchers and/or designers can thereby ensure the alignment between learning objectives and assessment tasks, enabling the capture of accurate estimates of students' knowledge, abilities, and attributes from GBA (Ke & Shute, 2015; Plass et al., 2015).

Another way to obtain accurate estimates of competency states and learning is to employ an appropriate statistical methodology to process GBA data. Currently, BNs are popular because they can accommodate a wide range of models (from simple to complex), generate real-time estimates accurately, and represent statistical relationships graphically and conveniently (Kim, Almond, & Shute, 2016; Levy, 2016; Mislevy et al., 2014). Researchers can extract copious amounts of GBA data from log files or databases. One downside of log files, though, is readability—especially when they capture lots of data that are both relevant and irrelevant to the research. One solution to this problem is to modify log files such that they capture only specific evidence (see Shute & Wang, 2016). An alternative approach is to develop a generic log file structure that can be applied to different games to handle data storage and extraction conveniently (see Hao, Smith, Mislevy, von Davier, & Bauer, 2016).

Practical Implications

An accurate and dynamic GBA can also enable timely scaffolding for learners (i.e., specific learning supports at the right time), thus providing an adaptivity feature in games (Plass et al., 2015; Virk, Clark, & Sengupta, 2015). For example, based on learners' current competency estimates from their performances, the game can adjust task difficulty to levels appropriate to the learners (Kanar & Bell, 2013; Sampayo-Vargas, Cope, He, & Byrne, 2013). Moreover, based on valid inferences, timely and individualized feedback can be presented to enhance learning (Cheng et al., 2015; Gobert, Sao Pedro, Raziuddin, & Baker, 2013; Shute, Leighton, et al., 2016), especially to support struggling learners (Baker et al., 2016). One thing to keep in mind when presenting various forms of feedback to learners is the cognitive load imposed by various representations and information-processing requirements (Adams & Clark, 2014; Lee, Plass, & Homer, 2006; Virk et al., 2015). Also, construct-irrelevant variables (e.g., prior gaming experience) should be controlled to reduce disruption to the gameplay experience (Dicerbo et al., 2017).

Additionally, it is important to consider the accessibility of GBA data. Researchers have argued that learners and teachers should have access to diagnostic data—for students to monitor their learning progress and to help teachers figure out when and how to intervene as warranted (Clarke-Midura & Dede, 2010; Shute, 2011; Timmis et al., 2016). Ethical issues should also be taken into account (Pardo & Siemens, 2014; Shute, Leighton, et al., 2016; Timmis et al., 2016), such as answers to the following questions: How can the student data be protected? Who owns the data and for how long? How can the data be used to best advantage? Lastly, to integrate teaching, learning, and assessment, researchers advocate close collaboration during GBA design among game designers, researchers, psychometricians, subject matter experts, and other stakeholders (Leighton & Chu, 2016; Mislevy et al., 2014; Plass et al., 2015).

Limitations and Future Research

There are several limitations of GBA that will need to be addressed in future studies. The first issue concerns what exactly GBA is. Theoretical papers are needed to clearly define it and describe its various types and distinctive features. For example, the boundary between GBA and simulation-based assessment is not clear. Is GBA a subcategory of simulation-based assessment only with higher levels of interactivity (de Klerk et al., 2016), or are the two overlapping (Levy, 2013)?

A second issue concerns the best statistical tools and analyses to be used to collect and process GBA data. Processing massive and complex gameplay data is difficult, especially when the data involve collaborations (Hao et al., 2016; Leighton & Chu, 2016; Nelson et al., 2011). Thus, figuring out how to effectively combine exploratory techniques (e.g., educational data mining) with approaches that are more conceptual (e.g., ECD) will benefit GBA research. An additional issue concerns reusability and cost-effectiveness (Moreno-Ger, Burgos, Martínez-Ortiz, Sierra, & Fernández-Manjón, 2008). Building a well-designed GBA is time consuming and usually domain-specific. Thus, the applicability of one GBA to other games or disciplines remains an underresearched area (Baker et al., 2016; Wang et al., 2015). The last question involves fairness. It is important that a GBA not favor any particular population (e.g., males vs. females, gamers vs. nongamers) and benefit every student equally (Dicerbo et al., 2017; Kim & Shute, 2015b; Timmis et al., 2016). However, studies on fairness of GBA are sparse.

One of the main affordances offered by well-designed games is that they are highly engaging. Similarly, well-designed GBAs are engaging, in addition to being able to render valid and reliable inferences about students' competencies during gameplay. The vision is to design high-quality, dynamic GBAs that are engaging, adaptive to individual needs, and can support learning (Shute, Ke, & Wang, 2017; Shute, Leighton et al., 2016).

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21 Learning Analytics for Games

V. Elizabeth Owen and Ryan S. Baker

Introduction: Learning Analytics and Educational Game Applications

Learning analytics (LA) and educational data mining (EDM) represent a host of education-specific methods for exploring and mining big data (US Department of Education, 2012) that can be used to enhance learning design and learning outcomes. In recent literature, EDM and LA have been discussed together as a converging set of methods for interpreting large streams of data from educational contexts (Baker & Siemens, 2014). While there are differences between the research questions these two communities ask, for the purposes of this chapter they can be treated as interchangeable. (For brevity in subsequent sections of this chapter, we will therefore refer to the collective set of methods as learning analytics or LA.)

EDM and LA have drawn from methods originally developed in a range of communities, from data mining and analytics in general and from psychometrics and educational measurement (Baker & Siemens, 2014), as well as increasingly producing methods unique to these research communities. The methods used in these communities can be divided into five major categories: prediction, structure discovery, relationship mining, discovery with models, and visualization. Prediction modeling infers an outcome or measure of interest (i.e., a predicted variable) when given input data (i.e., predictor variables) via a range of potential algorithms. In contrast, structure discovery “attempts to find structure in the data without an a priori idea of what should be found,” using methods such as clustering, factor analysis, and network analysis (Baker & Siemens, 2014, p. 258). Relationship mining is used to discover relationships between variables in a large dataset, leveraging approaches such as correlation mining, association rules, and sequential pattern mining. Discovery with models involves layering methods, often utilizing the results of one data-mining analysis within another to optimize insights. Finally, visualization is designed to express data visually to elucidate patterns (e.g., color-coded heat maps and graphics of trajectories over time with learning curves). These five categories, explored more deeply in the next section, provide important insights into game-based learning and map to specific development phases for optimal data-driven insights throughout the design process.

In the context of serious games, a substantial base of recent empirical research has utilized many of these learning analytics methods—particularly visualization, structure discovery, relationship mining, and prediction. As learning designers increasingly attend to event-stream data to inform iterative design (e.g., Kerr, 2015), these methods can be mapped to various stages of game development to support data-driven design for learning and engagement. In early-development alpha stages, when game design may be nascent, implementing basic data collection and using visualization can help uncover basic player interactions for improved core mechanics, user interface (UI), user experience (UX), and learning design. Structure discovery and relationship mining can uncover deeper player patterns as mechanics are solidified in beta phases; for example, results can help isolate points of attrition or bottlenecks in the game, identifying larger patterns of player navigation or strategy across game levels. Finally, late beta and final release analyses utilizing prediction can identify key predictors of target behaviors (e.g., game success, strategy, or engagement) to support final polish as well as provide insight that enables player-adaptive personalized paths through the learning space.

These learning analytics methods are discussed in greater depth later, setting a foundation for a review of current research in game-based learning analytics with implications for data-driven design. The following sections discuss overall methods of LA/EDM and potential alignment with learning game development stages, and review applications of these analysis methods in recent game-based learning research.

Overview of Learning Analytics / Educational Data Mining

Baker and Siemens (2014) divide learning analytics into a set of five main categories, building on an earlier review by Baker and Yacef (2009).

The first of these five categories is prediction. In prediction modeling, the researcher's goal is to create a model that can make inferences about a single variable, the predicted variable, from some combination of other variables, the predictor variables. The predicted variable may be a variable that can be easily collected for a small sample of data but cannot be collected at a larger scale. Alternatively, it may be some future outcome that is desirable to predict before it comes to pass, for example to drive early intervention. Either way, a model is created based on this sample of data, is validated to give confidence that it will function correctly on new data, and is then applied to new data. Three types of prediction are common in LA/EDM: classification, where a binary variable or multicategory variable is predicted; regression, where a number is predicted; and latent knowledge estimation, where student knowledge is assessed (typically as a probability between 0 and 1, typically based on correctness data that is itself binary).

The second of the categories in Baker and Siemens (2014) is structure discovery, which uses algorithms that attempt to discover structure in data with no specific variable as a focus. Within LA/EDM for game-based learning, the categories of cluster analysis, network analysis, and domain structure discovery are particularly prominent. In cluster analysis, the researcher attempts to use automated processes to discover which data points group together naturally, dividing the dataset into groups of data points, referred to as clusters. Cluster analysis is of particular value when the categories of interest among a dataset are not known a priori. In domain structure discovery, the structure of content is discovered automatically. For example, in a set of items, problems, or tasks, it may be possible to determine which problems involve some of the same content (perhaps skills, concepts, or strategies), such that performing well on one problem implies performing well on the other problem. In such a framework, it is possible to search for partial overlap of content—situations where problems A and B share skill Alpha but problem B also shares skill Beta with problem C. It is also possible to find prerequisite relationships, where successful performance on problem A implies successful performance on problem B but not vice versa. In network analysis, more complex networks of relationships between data points are investigated. For example, the paths a player might take through a specific puzzle might be turned into a graph and then subjected to network analysis to predict the best move a player might make next. A fourth type of structure discovery, common in other areas of LA/EDM but less common in game-based learning, is factor analysis, where the relationship between variables is analyzed in order to determine which variables can be combined into a smaller number of latent factors. (Factor analysis is sometimes used to analyze test data for domain structure discovery but is not frequently used in game-based contexts that are more complex, where students are learning as well as demonstrating their skill.)

The third category in Baker and Siemens (2014) is relationship mining. Referred to in that review as the "most common category of EDM research" (Baker and Siemens, 2014, p. 260), relationship mining is generally common in LA/EDM research on game-based learning as well. There are four broad categories of relationship mining, each of which has been conducted in the context of educational games. In the first, association rule mining, the software automatically finds if-then relationships where if a specific variable/value pair (or set of pairs) is seen, another specific variable/value pair usually accompanies it. In the second category, sequential pattern mining, association rules are found, with the additional criterion that the "then" part of the rule must occur after the "if" part of the rule. In correlation mining, a large number of variables are checked for correlation relationships between them, with post hoc statistical controls used to reduce the probability of finding spurious findings. Finally, in causal data mining (a method whose conclusiveness remains under debate), patterns of covariance are used to determine whether one event in a sequence of events is statistically likely to be the "cause" of a second, later event.

The fourth category in Baker and Siemens (2014) is discovery with models. Within discovery with models, a variable or set of variables is created through LA/EDM—using prediction modeling or clustering, for instance—and then used in a second analysis. For example, building a model of student disengagement for a game or simulation and then studying how that variable correlates to eventual student success in the game would be an example of discovery with models.

The fifth category in Baker and Siemens (2014) is visualization, referred to in that paper as "distillation of data for human judgment" (Baker and Siemens, 2014, p. 260). Visualizations of data can elucidate patterns in a way that is easily processed visually, at best representing high-dimension data in a simple, digestible presentation (Tufte, 2001). In the context of learning analytics, these can take the form of descriptive statistical charts, simple learning curves, heat maps, and radial visualizations. These have been used in LA/EDM for games, often in conjunction with other categories of methods discussed here; several examples are given in the next section, which discusses specific applications of these methods to serious games for learning insights and data-driven design. We highlight categories of methods commonly used in recent research, including visualization, structure discovery, relationship mining, and prediction.

Learning Analytics for Serious Games: Recent Applications of Methods

Learning analytics methods—especially visualization, structure discovery, relationship mining, and prediction—can support deep insight into playful learning patterns, as well as enhance design iteration for optimal learning and engagement when applied during various stages of game development. These investigations can be mapped to phases of design and game production in sync with preexisting game refinement cycles to fuel data-driven, iterative design for engaged learning. In the early stages of development (i.e., the alpha phase), data framework definition and visualization analytics can be valuable in supporting formative design; structure discovery and relationship mining can uncover deeper player patterns as mechanics are solidified in beta phases; and predictive modeling can support final game production by providing prediction of learning and behavior detection for in-game adaptivity in support of learning pathways. It's worth noting that, like best practices of Agile game development (https://www.scrumalliance.org), this alignment is flexible, with potential to extend application of analysis methods into multiple stages of development to support design as needed. In doing so, these event-stream analyses can complement ongoing qualitative research (e.g., observations, think-alouds, and interviews) in informing iterative improvement. The following subsection reviews recent research using these types of learning analytics methods in serious games to investigate student play patterns, with discussion of the insights provided into game-based learning and potential implications for data-driven design.

Early Development: Learning Data Collection and Visualization

In the early phases of game development, in which core mechanics and basic design may still be in their nascent stages, data framework design and visualization of basic user interactions can help game designers understand how players initially are approaching the game and support formative thinking about learning, games, and assessment mechanics. This can be particularly beneficial in conjunction with qualitative user testing (e.g., observations, think-alouds, and interviews) to support a well-rounded understanding of initial playful learning experiences, informing effective iterative design. This section discusses the benefits of a strong learning data foundation in early game design, as well as applications of learning analytics visualization in serious games.

Learning game data frameworks Event-stream data collection in serious games is an important undertaking and is foundational to analyses that provide actionable insight. Any process of making meaning out of data, whether involving thorough feature engineering or more bottom-up processes, is dependent on the integrity, quality, and scope of the original data. Recent efforts in structuring learning game data delineate the need for comprehensive, clearly organized, and design-aligned data collection (see Chung, 2015; Danielak, 2014; Hao et al., 2016; Serrano-Laguna et al., 2017). ADAGE (Assessment Data Aggregator for Game Environments), an event-stream data framework designed specifically to support embedded assessment and educational data mining, provides one approach tailored to serious games (Halverson & Owen, 2014). ADAGE collects comprehensive game events and player interactions enriched with contextual data, while providing salient performance data aligned with key learning mechanics. This kind of comprehensive data allows multiple methods of analysis in game-based learning investigations. Clear, design-aligned data output provides clear reference to the game's design of learning mechanics; when data are interpretable in this fashion, outcomes of analysis can be more easily translated to direct feedback into design. A consistently labeled series of event-stream interactions supports aggregation of data for analysis and feature engineering—a critical element of robust modeling in many approaches to learning analytics (e.g., Guyon & Elisseeff, 2003; Sao Pedro, Baker, & Gobert, 2012). This applies for analytics in a single game and is also vital for scalable analysis and adaptivity across a system of multiple games that interplay to jointly support student learning.

Finally, early implementation of a strong data collection framework can support good learning design practices in clearly aligning data-producing game mechanics with targeted learning objectives. A well-designed game will have game events that can be interpreted directly in terms of the types of competencies and learning that the designer wants to measure (e.g., Shute & Kim, 2014). Consideration of this alignment during the early design stages can support good learning design and more robust event-stream data for analysis.

Data visualization These comprehensive, design-aligned data structures in early design enable analysis for data-driven design in the alpha game-development phases. In particular, visualizations and descriptive statistics can support early game development in revealing basic player interaction with the game (e.g., identification of bugs, bottlenecks, and core mechanic interaction) for improved UI/UX and learning design. Visualization methods can consistently support subsequent stages of game development as well.

As a growing field, learning analytics for serious games has set a foundation in data visualization for game analysis, including capturing movement within the game space (UI and game map), interaction with core learning mechanics at different stages of the game, and even aiding capture of biometrics and metacognitive student behavior. To this end, Wallner and Kriglstein (2015) detail a taxonomy of visualization types for comparative analysis of serious game data based on juxtaposition (e.g., comparing two player groups side by side), superposition (stacking visualizations of each group), and explicit encoding (visually encoding differences between datasets), particularly using star plots, network diagrams / graph analysis, heat maps, and color overlays.

Indeed, such visualizations have supported analysis of player movement within the game space in related research. For example, Kim et al. (2008) developed a game analysis method that combined player survey pop-ups and heat mapping, which allowed identification of game areas of frustration and high failure. This tool was used to fix areas in a real-time strategy game with abnormally high rates of player death; the authors found that the modifications increased both player performance and player engagement. Similarly, research at Games+Learning+Society (GLS), a learning game development and research group at the University of Wisconsin–Madison (http://www.gameslearningsociety.org/), has used visualization to improve the early design of serious games, creating heat maps of usage at the main game level in order to intuit areas of high traffic for optimal placement of critical player resources and to iterate on map design (e.g., Ramirez, 2016). Data visualization of player navigation through game levels can also be utilized for early game development, especially network diagrams or "state space diagrams" that show paths through a network of game states. In a study of interaction with a level selection menu, network diagram visualizations isolated game maps with low traffic and subsequently informed improvements of UI design in the early development stages to support higher usage (e.g., Beall et al., 2013). Similarly, network diagrams were used as part of a suite of visualizations to understand play in a fractions game (Butler & Banerjee, 2014) utilizing a node-edge visualization along with heat maps of game tool use to compare progress between players at the same level. In the physics puzzle game *Quantum Spectre* (https://terctalks.wordpress.com/tag/quantum-spectre-game/), descriptive statistics of player interactions (including game error types and number of moves in a level) were employed, along with a state space diagram, to better understand player dropout and improve design (Hicks et al., 2016).

SimCityEDU (https://www.glasslabgames.org/games/SC) was also studied using state space diagrams to show archetypal student paths through the simulation space (Institute of Play, 2013). Additional visualization of progress in nonlinear learning games builds on this idea to visualize different possible states of play. Aghababyan, Symanzic, and Martin (2013) move beyond basic nodes and edges to customize a tree visualization incorporating timeline, progress along visually fixed markers specific to each game level, and the student win state. These visualizations, which tend to focus on user interaction one game level at a time, have utility in early stages of development, and in subsequent stages, to inform iterative design about where and how players struggle and how they can be scaffolded in reaching successful performance.

In related analyses, other methods of visualization have been utilized to show student progress (often related to performance) across multiple stages within a game. Using a radial sunburst style visualization, for example, Cooper et al. (2010) showed different player strategies across multiple levels of the science game *Foldit* (https://fold.it), designed to enable player production of accurate protein structure models. Dimensions of the radial visualization included time elapsed, summative puzzle performance, and tool usage during different slices of play—information valuable for iterative design targeted toward supporting multiple play pathways to success. GLS researchers have used similar descriptive statistics (paired with discourse analysis) to investigate multimodal data streams for game-based learning during multiday play workshops for a middle school biology game (Anderson et al., 2016). Results suggested that students initially looked up more key words in the in-game almanac and tapered off this behavior toward the end of play, transitioning from seeing these words in a glossary to adopting these biology terms in social discourse over time. Other visualizations summarizing progress across learning game levels have been used as student-facing communication to encourage future success. As part of an intervention to support a growth mindset in players of a fractions game (http://centerforgamescience.org/blog/portfolio/refraction/), a summary screen of progress for students (given at key points in play), paired with reward points (O'Rourke, Peach, Dweck, & Popovic, 2016), resulted in greater student retention and persistence. Other player-facing progress visualizations across game levels include work in commercial games such as *Civilization* (a game used for learning in classroom contexts in recent research—e.g., Squire, 2011). *Civilization V* (http://www.civilization5.com/), for example, has persistent player progress visualizations in the form of network diagrams (for technology researched) and simple totals of vital game resources (e.g., gold, science points, and cultural strength). Visualizations across game levels, including those that are user facing, have strong potential to inform game progression design and support desirable player behavior.

Some game data visualizations sweep further, aiming to provide data visualizations across games. In analyzing differences between populations across two games used by different populations, a state space visualization and descriptive statistics were used to elucidate game-level interaction for juxtaposition of groups (O'Rourke, Butler, Liu, Ballweber, & Popovic, 2013), ultimately showing that younger users were interacting with the game in a less focused way (thus limiting success) in comparison with older players. Generalizable game visualization tools have also been created—including *Playtracer*, which was built to analyze play traces visually, creating a generalized heat map that applies to any game with discrete state spaces (Andersen, Liu, Apter, Boucher-Genesse, & Popović, 2010). Although not applicable to all genres, and difficult to scale for highly complex games with many possible actions, it can show progression in a similar visualization across games for an accessible comparison of play. This potentially supports the development of player profiles and allows insight around common states of interaction. With a similar goal in affording clear comparison of play, Scarlatos and Scarlatos (2010) built a cross-game tool that visualizes play progress as a glyph, the shape of which (standardized across games) can be interpreted to determine desirable progression or failure. Such generalizable tools have limits, since they essentially equate win states across games, even though they may not actually be comparable in terms of difficulty or rigor; they also may not apply across genres or platforms. However, for assessing student play style across games, especially in large systems that contain multiple games designed to work together, these analytics can have value for informing iterative design and player profile formation. In their early stages, they may also support understanding where attrition points occur in gameplay to aid iterative design improvement.

Building on basic game interactions, visualization and descriptive statistics can also be used to illuminate player patterns orthogonal to the click-by-click log files, such as biometric trends. Eye tracking is a capability that commercial games are increasingly developing—particularly in games with a camera built into the platform device interface (e.g., the PC game *Rise of the Tomb Raider*; https://www.gamespot.com/rise-of-the-tomb-raider). Leveraging this potentially powerful data source, Kiili, Ketamo, and Kickmeier-Rust (2014) evaluated serious-game eye-tracking data using statistical analysis and heat maps, which revealed that low performers directed too much attention to areas of little relevance compared to high performers. Other forms of biometrics, applicable at the intersection of neuroscience and game-based learning behavior (e.g., Beall et al., 2013), have looked to visualizations of brain activity for insights about learning. One such study (Baker, Martin, Aghababyan, Armaghanyan, & Gillam, 2015) took cortical measurements of brain activity during play of a fractions game, with heat-map results revealing brain activity similar to that from traditional mathematical activities in the same domain. Used in conjunction with user testing and event-stream data analysis, these biometric visualizations can support early testing of cognitive engagement and iterative design choices to optimize user attention.

Inferences about player behavior and affect can also be made in conjunction with play, which can begin to be explored through visualization and descriptive statistics—for example, through distilling event-stream data into snapshots of play in the form of *text replays* (Baker, Corbett, & Wagner, 2006), which are designed to support human evaluation of player behaviors (e.g., Owen, 2014). Descriptive statistics have also been useful for representing coded instances of strategic behavior in games (see Berland & Lee, 2011; Steinkuehler & Duncan, 2008), elucidating favorable and unfavorable student patterns useful for consideration in early design and beyond. These kinds of descriptive visualizations can also set a foundation for building behavior models in relationship with play data for more complex analyses in later stages.

Beta Development: Structure Discovery and Relationship Mining

In more advanced phases of game development (i.e., beta design stages), the LA method categories of structure discovery and relationship mining can be used to understand player decisions on a deeper level—with the capability to identify sequence and attrition points, as well as interaction patterns related to engagement, success, and strategy. These analytics offer an opportunity to refine game design to support successful student trajectories based on organic play patterns (rather than relying on "ideal" pathways defined a priori) and can continue to offer insight throughout the final stages of design.

Recent research has utilized structure discovery methods such as cluster analysis with large amounts of event-stream game data to reveal strategies and interactions related to game success. Kerr and Chung (2012) explored clustering techniques in the elementary math game *Save Patch* in order to capture the kinds of strategies used by students. Building on this work, in which fuzzy clustering was most useful, the game design was revised to minimize the ability to pass a level by using incorrect mathematical strategies. Empirical testing of the new version of the game revealed that the changes resulted in more correct strategies in fraction problem solving used to pass levels of the game, with more positive student reception for the updated version (Kerr, 2015). In an analysis of another game in the same domain of fractions, hierarchical clustering was used to group player strategy. This analysis demonstrated that exploration of in-game splitting (i.e., partitioning a whole into equal-sized parts) mechanics significantly improved students' fraction understanding, and that splitting strategy improved from early to late gameplay (Martin et al., 2015). Other game-based analysis work has applied methods such as latent class analysis (LCA) to derive emergent student groups for play profiles; in a recent study of the learning game *Physics Playground*, LCA results derived emergent player trajectories indicative of student play styles, including achievers, explorers, and disengaged players (Slater, Bowers, Kai, & Shute, 2017). Other research into the psychology of play has also mined the structural relationships within play profile attributes in an online game, using factor analysis to distill 10 motivations for play grouped into achievement, social, and immersion components (Yee, 2006). In related structure discovery with game data in the GlassLab game (https://www.glasslabgames.org/games/AA-1) *Mars Generation One* (designed to build argumentation skill in middle school players), factor analysis was used to distill survey-based game measures of engagement and self-efficacy, which were then aligned with event-stream data in predicting self-reported learning (Owen et al., 2015).

Relationship mining for game analysis has been used to discover associations between play variables. Recent research has explored association patterns between player profile attributes and in-game data, finding evidence that player types and psychological attributes provide key insight into play behavior (e.g., Canossa, Badler, El-Nasr, Tignor, & Colvin, 2015; Yee, Ducheneaut, Nelson, & Likarish, 2011). Also exploring associations between game data and out-of-game behavior, Andres et al. (2014) found that affect (specifically the state of being confused) is negatively related to high in-game achievement and efficiency in physics problem solving.

Sequence mining has also been a particularly popular method, as play data can offer a rich and varied trajectory of sequential player decisions, particularly for nonlinear games. Exploration of n-grams (i.e., sequences of play behavior, in the context of serious games), for example, has supported adaptive level progression tailored to the player's history of in-game behavior (e.g., Butler, Andersen, Smith, Gulwani, & Popović, 2015). In a serious math game for elementary school students, n-gram analysis was utilized for mining the most frequent sequential play patterns (Aghababyan, Martin, Janisiewicz, & Close, 2016) as an extension of understanding strategic play trajectories in a serious game (Martin et al., 2015). N-gram analysis has also been paired with other methods for increased insight into play. Owen (2014) pairs bigram and trigram counts of in-game activity with correlation mining, showing that specific productive failure trajectories are significantly associated with learning gains in a middle school biology game. N-gram analysis has also been used in combination with logistic regression in the study of a role-playing game (RPG) to show trajectories of play that differentiate high-expertise players from those with lower expertise (Chen et al., 2015). Moving into probabilistic modeling, Markov models have been used to show the probability of a player transitioning from one state to another in gameplay (e.g., the likelihood of moving from one game level to the next or to oscillate between states of success and failure). In the context of a middle school science game, for instance, a first-order Markov model was employed to determine the stages of play in which students are most likely to quit (Owen, Shapiro, & Halverson, 2013). Hidden Markov modeling (HMM) has been used to explore latent states of student understanding during play across multiple game platforms—including computer games (e.g., Clark, Martinez-Garza, Biswas, Luecht, & Sengupta, 2012) and digitally interactive tabletop games (e.g., Tissenbaum, Berland, & Kumar, 2016). Tissenbaum, Berland, and Kumar (2016) mined the sequence of player circuit forming as unproductive or productive with an HMM, identifying productive learning trajectories of students who had started in unproductive states and moved to success within the context of a game-based museum exhibit. Overall, structure discovery and relationship mining can thus support understanding of play trajectories connected with positive game performance and learning outcomes. While these are valuable insights for understanding student behavior on their own, they can also inform iterative design to support such trajectories with adaptive leveling or enhanced scaffolding at key points in the game.

Late Beta and Final Release: Predictive Learning Analytics

In the final stages of game development, including late beta and final release, learning analytics can be used to predict in-game actions and performance most characteristic of learning. Predictive modeling can reveal a great deal about student growth during play and mine key predictors of behavior from the game data event stream—especially in combination with ongoing insights from previous-stage analytics, including visualization, structure discovery, and relationship mining. These investigations have the potential to support field-enriching inferences about learning and behavior, as well as fuel data-driven design through real-time detection of students' pathways to inform adaptive, personalized game progression.

Various methods of prediction have been used in analyzing serious-game data, from canonical statistical models (e.g., linear regression and HLM; see Marascuilo & Serlin, 1988) to data-mining algorithms for classification and regression (Baker, 2010). Utilizing different prediction models to investigate strategy use in a real-time strategy (RTS) game, Weber and Mateas (2009) evaluated various algorithms (including linear regression, additive logistic regression, J48 classification, and M5′ regression). They found that overall M5′ had the smallest relative error in predicting timed player construction of key game resources. Prediction has also been leveraged in the form of HLM for evaluation of collaboration and competition in games, with recent research showing that competition increased in-game math learning compared to individual play, and both collaboration and competition elicited greater situational interest and enjoyment (Plass et al., 2013). In another math game, researchers used predictive modeling with logistic regression to show that different kinds of fraction errors are predictive of learning outcomes (Kerr & Chung, 2013)—implying that in-game scaffolding design should not treat all errors equally. In further predictive modeling, survival analysis was used to investigate the game *Quantum Spectre*, specifically pinpointing conditions of play that influenced player dropout with an accelerated failure time model (Hicks et al., 2016). Prediction has also been used to support adaptive gameplay, as seen in the use of reinforcement learning to predict optimal player scaffolding through narrative in the learning game *Crystal Island* (Rowe & Lester, 2015). Similarly, adaptive learning design has been explored using decision trees in gamelike e-learning environments, using prediction to prescribe customized learning paths through the system (e.g., Lin, Yeh, Hung, & Chang, 2013).

Recent research in the application of LA/EDM to learning games utilizes predictive data mining to build event-stream detectors of behavior, a method first applied in the context of intelligent tutoring systems (e.g., Baker, Corbett, & Koedinger, 2004). With the increasing availability of log file data in digital learning games, event-stream detectors have been leveraged to more deeply understand and predict player behavior. In the context of a physics game, for example, detectors of affective states and off-task behaviors were built based on video logs, and event-stream data were used to predict behavior and affect throughout play (Kai et al., 2015). Results showed distinct event-stream behaviors indicative of each state (e.g., boredom's predictors included number of items "lost" or moved off-screen during play and amount of time elapsed between actions). The video-based detectors were more accurate than the interaction-based detectors but could not be used in many situations (because of occlusion of the face, for example, a joint detector using both types of data was more effective than either type alone; see Bosch et al., 2015). Also focusing on players' approaches to games, other researchers have created game-based detectors of behaviors related to goals and strategy. DiCerbo and Kidwai (2013) built a detector to register whether players were serious about completing a game's quests, with implications for enabling design support of players in completing game objectives. Productive failure and boundary testing have also been modeled in recent studies, with a detector of thoughtful exploration built for a middle school biology game (Owen, Anton, & Baker, 2016). The results gave insight into emergent player pathways in which failure was a healthy part of a trajectory to ultimate game success. The implication that many pathways can lead to learning has guided related work, as seen in a detector designed to capture an emergent strategy for level completion within the physics game *Impulse* (Asbell-Clarke, Rowe, & Sylvan, 2013).

Game-based detectors have also been used to predict learning performance based on in-game player choice. A prime example is measurement of science inquiry skill in a game-based virtual environment in which classifiers were used to detect students' learning of the science, technology, engineering, and mathematics (STEM) content during play (Baker & Clarke-Midura, 2013). Achievement in a physics game was also the subject of a recent prediction analysis in a physics game, with detectors built to predict in-game level completion at the highest level (gold) and a moderate level (silver). The findings suggested that gold achievers tended to be more efficient with time and resources than their silver-winning counterparts (Malkiewich, Baker, Shute, Kai, & Paquette, 2016). In related work, Rowe et al. (2017) leveraged detectors toward creating a valid computer-based assessment of implicit science learning using validated in-game measures as outcome variables in event-stream predictions of learning performance in physics games. Broadly, this detector-based approach has opened learning insight beyond simply looking at a pretest or posttest and treating the game as a black box. It enables understanding of the emergent event-stream interactions that support learning outcomes and target behaviors—and in turn creates the opportunity for design refinements that can support student growth moment by moment in play. It also creates strong potential for process-based assessment of learning, particularly in the context of complex skills and problem solving.

Overall, in support of iterative serious game design, learning analytics can leverage multimodal data streams for insights about learning and player patterns at various stages of development. The analyses reviewed here reflect recent trends in empirical game-based learning research—including usage of learning data frameworks and visualization, structure discovery, and relationship mining, as well as prediction methods—with applicability to progressive stages of design (i.e., alpha, beta, and final release).

Discussion and Conclusion

Learning analytics and educational data mining are a set of methods that can be used to fuel the advancement of educational games research through leveraging the rich data streams enabled by digital educational games, helping to finely tune data-driven design for personalized, engaging, game-based learning experiences. Challenges and opportunities for future work in game-based learning analytics at scale are constantly expanding, in parallel with advances in technology and increases in the sophistication of game delivery systems (e.g., 3-D, augmented reality, and virtual reality), leading to compelling playful learning experiences.

Implications

Applying LA to the complex, data-rich medium of serious games is a challenging endeavor with great potential for harnessing interest-driven learning (Squire, 2006; Steinkuehler, 2004). As the body of empirical work in this area grows, there is opportunity to advance theory in the context of this complex, engaging learning medium. As we explored in this chapter, empirical work modeling event-stream player patterns at scale has utilized core LA methods of visualization, structure discovery, relationship mining, and prediction. This growing base of research provides great opportunities for game-based application of a broader array of educational data-mining algorithms recently explored in different contexts, including probabilistic modeling, such as Bayesian knowledge tracing (Corbett & Anderson, 1995), and advanced predictive algorithms, such as deep learning (Botelho, Baker, & Heffernan, 2017). Experimental design and game experiences geared toward building research in learning sciences also has considerable potential—from expanding knowledge of areas such as embodied cognition (Abrahamson, 2009; Gee, 2008), to apprenticeship models (e.g., National Research Council, 2000; Steinkuehler & Oh, 2012), to learning epistemology (e.g., Hofer & Pintrich, 1997; Martinez-Garza & Clark, 2017).

Games also offer opportunity for expanding approaches to assessment and measurement in virtual learning environments (Mislevy et al., 2014). Good games—intrinsically motivating learning environments that provide just-in-time information through a series of well-ordered problems (Gee, 2003)—inherently provide occasion for players to discover the underlying rule system of games through boundary testing (e.g., Owen et al., 2016). This kind of exploration is an implicit norm in the medium of games, in which equally engaged players may interact differently with the system—often in ways designers themselves don't anticipate (Juul, 2013; Salen & Zimmerman, 2004; Squire, 2011). Therefore, analysis methods well matched to the game context and intent on capturing the most information about learner pathways can be best equipped to mine emergent player patterns. These kinds of methods native to EDM can be used in conjunction with more traditional assessments to expand approaches to rigorous competency measurement in complex gamelike environments (e.g., Baker & Clarke-Midura, 2013; Rowe et al., 2017).

Finally, forays into studying organic patterns of play also enable a critical application of learning analytics in serious games: data-driven design for personalized learning. As detailed in this chapter, iterative design based on emergent play patterns can support game development through multiple stages. Robust data frameworks, visualizations, and descriptive statistics can be helpful early on (e.g., alpha stages) in capturing basic player interactions while core mechanics, level design, and fundamental user experience are being shaped. Later, during beta development, structure discovery and relationship mining can be leveraged to streamline the player experience across multiple levels of play through identifying play sequence and attrition points, as well as interaction patterns related to engagement, success, and strategy. These methods can build on one another, supporting final application of predictive modeling within the late beta and final-release stages—and to inform user-adaptive play in highly evolved game design. For example, personalized game experiences can utilize prediction to provide different core content for players (e.g., Liu et al., 2013; Rowe & Lester, 2015) or inform game overlays for just-in-time scaffolding based on behavior detection (as proposed by DiCerbo & Kidwai, 2013). Mining organic predictive patterns of play allows personalized learning experiences for the player, which has significant implications for moment-to-moment engagement and system efficacy. Since serious games by definition have potential to teach while sustaining engagement, game-based application of LA methods can detect for learning as well as engaged behavior and afford personalization on both these dimensions. This analytics-fueled advancement in adaptive digital design has huge implications for serving a wide range of students—at massive scale—to support individualization and learning gains in both formal and informal learning environments.

Conclusion and Future Work

As noted, future work in game-based learning analytics affords increased opportunity for enhancing both theory and learner experiences and outcomes. Digital data streams afford investigation of learning patterns—through data that capture student process, not just a final answer—at a scale not previously possible in educational research. Advancement of technology is only fueling this potential, enabling even larger bodies of data through the advent of innovative game genres such as 3-D, augmented reality, and virtual reality. As these kinds of technologies reach players globally, a challenge presents itself to harness this potential and increase the size and scope of targeted studies. This future work is one link in a chain of challenges related to learning analytics and optimized design: leverage game-based engagement to create compelling and polished games for learning using emergent game genres, sustainably distribute these games to the desired population sample, utilize the technology to reach a larger number of students, and maintain development work long enough to meaningfully implement data-driven design. Successful navigation of these challenges may be possible as the realms of commercial and learning games converge in various forms, including: (1) widely used subscription-model learning games such as *ABCmouse* (https://www.abcmouse.com) and *ST Math* (http://www.stmath.com); (2) the modding of commercial entertainment games for learning such as *SimCityEDU*, *Words with Friends EDU* (https://wordswithfriendsedu.com), *Plants vs. Zombies EDU* (https://www.glasslabgames.org/games/PVZ); and (3) powerful tangential learning leveraged from existing commercial games such as *Minecraft* (https://minecraft.net/en-us), *Civilization*, and even *Assassin's Creed* (https://assassinscreed.ubisoft.com) (e.g., Berger & Staley, 2014). In these examples, highly polished games are sustainably created and distributed to a target audience, with potential for the study of data-rich environments that foster engaged learning. Still, the barriers to entry in any one of these models (particularly the third category) are substantial, and sustainable creation, research, and ongoing refinement of quality learning games remains a challenge.

In particular, clearly structured, comprehensive learning data is key to fruitful analysis (e.g., Halverson & Owen, 2014). As discussed in this chapter, interpretable, design-aligned data are critical for analysis feature selection, understanding analysis results, and using feedback to subsequently inform design. Building in such a framework early in development can also support best practices in learning design. However, such implementation takes planning, technological resources, and a viable event-stream data framework. Thus, building in this framework from the early stages of design or undertaking the nontrivial task of retrofitting after game completion can be formidable. Recent efforts in learning game data architecture have expanded the options and attempted to reduce implementation logistics (e.g., Chung, 2015; Danielak, 2014; Serrano-Laguna et al., 2017), but there remains opportunity for standardization and accessibility across the field.

Lastly, future work lies in adopting the best practices of commercial game development within the creation of learning games. In other words, in order to benefit from data-driven design, one has to engage in it. Even a relatively small investment of resources in an iterative, user-centric design approach, which is common in industry, can increase the quality of the learner experience (e.g., fail early and often, with both small-n qualitative playtests and larger event-stream analysis where possible). In the realm of serious games, this can make for substantially better products—ones that students may voluntarily play outside school or experimental conditions, potentially empowering interest-driven learning at an unprecedented scale. Through an increase in demand, such work might also increase the viability and sustainability of serious-game development models.

Overall, learning analytics applied to the complex medium of learning games can support advancement of theory in the field, adaptive game-based learning, and powerful crafting of an engaged learning experience through iterative, data-driven design. As we explored in this chapter, recent research has established a growing body of empirical game-based studies in learning analytics. These methods include visualization, structure discovery, and relationship mining, as well as predictive modeling—which, respectively, can support alpha, beta, and final-release stages of game development. In combination with a robust data collection framework, leveraging learning analytics throughout the design process and beyond is key to supporting students in personalized, engaging play experiences optimized for learning at scale.

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Contributors

Editors

Jan L. Plass is professor of educational communication and technology and the inaugural holder of the Paulette Goddard Chair of Digital Media and Learning Sciences in the Steinhardt School of Culture, Education, and Human Development at New York University. He has been codirecting the Games for Learning Institute since 2008, conducting research on the design of effective games for learning. He is the director of the Consortium for Research and Evaluation of Advanced Technology in Education (CREATE), which he founded in 2001. His research is at the intersection of cognitive science, learning sciences, and design, and seeks to enhance the effectiveness of interactive visual environments, especially simulations and games, for learning and cognitive skills development. He is the author of over 100 journal articles, chapters, and conference proceedings, and has given more than 170 presentations at academic conferences. He has been the principal investigator or co-principal investigator on over 30 research grants from the Institute of Education Sciences (IES), the National Science Foundation, the National Institutes of Health, Microsoft Research, the Motorola Foundation, the MacArthur Foundation, the Bill and Melinda Gates Foundation, EDUCAUSE, and Google Research. One of his current grants on designing and validating games to train targeted cognitive skills, funded by the IES, is a collaboration with Richard Mayer and Bruce Homer. He has served on the editorial review boards of some of the most highly ranked journals in his field, including *Journal of Educational Psychology*, *Educational Psychology Review*, *Computers in Human Behavior*, and *Journal of Computing in Higher Education*.

Richard E. Mayer is Distinguished Professor of Psychological and Brain Sciences at the University of California, Santa Barbara. His research interests are in applying the science of learning to education, with a focus on how to help people learn in ways such that they can transfer what they have learned to new situations. His research is at the intersection of cognition, instruction, and technology, with current projects on multimedia learning, computer-supported learning, and computer games for learning. He has served as president of Division 15 (Educational Psychology) of the American Psychological Association and vice president of the American Educational Research Association for Division C (Learning and Instruction). He is the winner of the E. L. Thorndike Award for career achievement in educational psychology, the Scribner Award for outstanding research in learning and instruction, the Jonassen Award for excellence in research in the field of instructional design and technology, the James McKeen Cattell Award for a lifetime of outstanding contributions to applied psychological research, and the American Psychological Association's Distinguished Contribution of Applications of Psychology to Education and Training Award. He was ranked as the most productive educational psychologist in the world in *Contemporary Educational Psychology* and as the most cited educational psychologist on Google Scholar. He has served as principal investigator or co-principal investigator on more than 40 grants, including recent grants from the Office of Naval Research, the Institute of Education Sciences, and the National Science Foundation. He is former editor of *Educational Psychologist* and former coeditor of *Instructional Science*, and he serves on the editorial boards of 12 journals, mainly in educational psychology. He is the author of more than 500 publications, including 30 books, such as *Learning as a Generative Activity*, *Computer Games for Learning*, *Applying the Science of Learning*, *e-Learning and the Science of Instruction* (4th ed.) (with R. Clark), *Multimedia Learning* (2nd ed.), *Learning and Instruction*:(2nd ed.), *Handbook of Research on Learning and Instruction* (2nd ed.) (coedited with P. Alexander), and *The Cambridge Handbook of Multimedia Learning* (2nd ed.) (editor).

Bruce D. Homer is associate professor of educational psychology and human development, and executive officer (chair) of the PhD program in educational psychology at the Graduate Center of City University of New York. He directs the Child Interactive Learning and Development (CHILD) Lab, is director of research at the Consortium for Research and Evaluation of Advanced Technologies in Education (CREATE), and is a primary investigator at the Games for Learning Institute (G4LI). His research investigates the ways in which cultural tools that communicate and transmit knowledge (e.g., language, literacy, and information technologies) transform cognitive development and learning. For over 20 years, he has also been studying the use of digital technologies for learning. In support of his research, he has received over 25 grants from various agencies, including the National Institutes of Health, the National Science Foundation, the Institute for Educational Sciences, as well as the MacArthur Foundation, Microsoft Research, and Google. He has authored over 60 journal articles, chapters, and conference proceedings, and has presented his research at academic conferences and invited talks around the world. Additionally, he has served as an educational and research consultant internationally for schools, companies, and nonprofit institutions, including PBS and the American Academy of Pediatricians.

Contributors

Roger Azevedo
University of Central Florida

Ryan S. Baker
University of Pennsylvania

Daphne Bavelier
University of Geneva

Amanda E. Bradbury
North Carolina State University

Pedro Cardoso-Leite
University of Luxembourg

Ruth Clark
Clark Training and Consulting

Michele D. Dickey
Miami University

Hamadi Henderson
City University of New York

Bruce D. Homer
City University of New York

Augustin Joessel
University of Geneva

Fengfeng Ke
Florida State University

Younsu Kim
Arizona State University

Charles K. Kinzer
Teachers College, Columbia University

Eric Klopfer
Massachusetts Institute of Technology

James C. Lester
North Carolina State University

Kristina Loderer
University of Munich

Richard E. Mayer
University of California, Santa Barbara

Bradford W. Mott
North Carolina State University

Nicholas V. Mudrick
North Carolina State University

Brian Nelson
Arizona State University

Frank Nguyen
Amazon

V. Elizabeth Owen
University of Wisconsin–Madison

Shashank Pawar
New York University

Reinhard Pekrun
University of Munich; Australian Catholic University

Jan L. Plass
New York University

Charles Raffaele
City University of New York

Jonathon Reinhardt
University of Arizona

C. Scott Rigby
Immersyve Inc.

Jonathan P. Rowe
North Carolina State University

Richard M. Ryan
Australian Catholic University

Ruth N. Schwartz
Quinnipiac University

Valerie J. Shute
Florida State University

Randall D. Spain
North Carolina State University

Constance Steinkuehler
University of California, Irvine

Chen Sun
Florida State University

Frankie Tam
New York University

Michelle Taub
University of Central Florida

Meredith Thompson
Massachusetts Institute of Technology

Steven L. Thorne
Portland State University and the University of Groningen

A. M. Tsaasan
University of California, Irvine

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