J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*

HUMAN CENTERED DESIGN

This article is concerned with designing products and systems using a methodology called *human-centered design* (1,2). Human-centered design is a process of ensuring that the concerns, values, and perceptions of all stakeholders in a design effort are considered and balanced. Stakeholders include users, customers, evaluators, regulators, service personnel, and so on.

Human-centered design can be contrasted with user-centered design (3,4,5,6). The user is a very important stakeholder in design, often the primary stakeholder. However, the success of a product or system is usually strongly influenced by other players in the process of design, development, fielding, and ongoing use of products and systems. Human-centered design is concerned with the full range of stakeholders.

Considering and balancing the concerns, values, and perceptions of such a broad range of people presents difficult challenges. Ad hoc approaches do not consistently work—too much drops through the cracks. A systematic framework, which is comprehensive but also relatively easy to employ, is necessary for human-centered design to be practical. This article presents such a framework.

Design Objectives

There are three primary objectives within human-centered design. These objectives should drive much of designers' thinking, particularly in the earlier stages of design. Discussions in later sections illustrate the substantial impact of focusing on these three objectives.

The first objective of human-centered design is that it should *enhance human abilities.* This dictates that humans' abilitites in the roles of interest be identified, understood, and cultivated. For example, people tend to have excellent pattern recognition abilities. Design should take advantage of these abilities, for instance, by using displays of information that enable users to respond on a pattern recognition basis rather than requiring more analytical evaluation of the information.

The second objective is that human-centered design should help *overcome human limitations.* This requires that limitations be identified and appropriate compensatory mechanisms be devised. A good illustration of a human limitation is the proclivity to make errors. Humans are fairly flexible information processors—an important ability—but this flexibility can lead to "innovations" that are erroneous in the sense that undesirable consequences are likely to occur.

One way of dealing with this problem is to eliminate innovations, perhaps via interlocks and rigid procedures. However, this is akin to throwing out the baby with the bath water. Instead, mechanisms are needed to compensate for undesirable consequences without precluding innovations. Such mechanisms represent a human-centered approach to overcoming the human limitation of occasional erroneous performance.

The third objective of human-centered design is that it should *foster human acceptance.* This dictates that stakeholders' preferences and concerns be explicitly considered in the design process. While users are certainly key stakeholders, there are other people who are central to the process of designing, developing, and

operating a system. For example, purchasers or customers are important stakeholders who often are not users. The interests of these stakeholders also have to be considered to foster acceptance by all the humans involved.

Design Issues

This article presents an overall framework and systematic methodology for pursuing the above three objectives of human-centered design. There are four design issues of particular concern within this framework.

The first concern is *formulating the right problem*—making sure that system objectives and requirements are right. All too often, these issues are dealt with much too quickly. There is a natural tendency to "get on with it," which can have enormous negative consequences when requirements are later found to be inadequate or inappropriate.

The second issue is *designing an appropriate solution.* All well-engineered solutions are *not* necessarily appropriate. Considering the three objectives of human-centered design, as well as the broader context within which systems typically operate, it is apparent that the excellence of the technical attributes of a design are necessary but not sufficient to ensure that the system design is appropriate and successful.

Given the right problem and appropriate solution, the next concern is *developing it to perform well.* Performance attributes should include operability, maintainability, and supportability—that is, using it, fixing it, and supplying it. Supportability includes spare parts, fuel, and, most importantly, trained personnel.

The fourth design concern is *ensuring human satisfaction.* Success depends on people using the system and achieving the benefits for which it was designed. However, before a system can be used, it must be purchased, usually by other stakeholders, which in turn depends on it being technically approved by yet other stakeholders. Thus, a variety of types of humans have to be satisfied.

Design Methodology

Concepts such as user-centered design, user-friendly systems, and ergonomically designed systems have been around for quite some time. Virtually everybody endorses these ideas, but very few people know what to do in order to realize the potential of these concepts. What is needed, and what this article presents, is a methdological framework within which human-centered design objectives can be systematically and naturally pursued.

Design and Measurement. What do successful products and systems have in common? The fact that people buy and use them is certainly a common attribute. However, sales is not a very useful measure for designers. In particular, using *lack* of sales as a way to uncover poor design choices is akin to using airplane crashes as a method of identifying design flaws: This method works, but the feedback provided is a bit late.

The question, therefore, is one of determining what can be measured early that is indicative of subsequent poor sales. In other words, what can be measured early to find out if the product or system is unlikely to fly? If this can be done early, it should be possible to change the characteristics of the product or system so as to avoid the predicted failure.

This section focuses on the issues that must be addressed and resolved for the design of a new product or system to be successful. Seven fundamental measurement issues are discussed, and a framework for systematically addressing these issues is presented. This framework provides the structure within which the remainder of this article is organized and presented.

Measurement Issues. Figure 1 presents seven measurement issues that underlie successful design (7). The "natural" ordering of these issues depends on one's perspective. From a nuts and bolts engineering point of view, one might first worry about testing (i.e., getting the system to work) and save issues such as

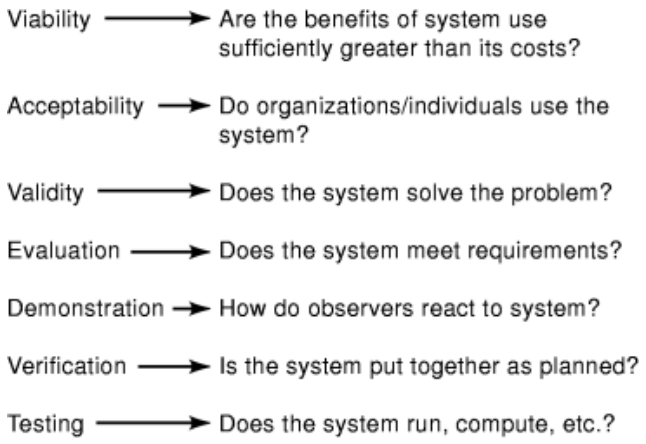

Fig. 1. Measurement issues that must be addressed to ensure success in design.

viability until much later. In contrast, most stakeholders are usually first concerned with viability and only worry about issues such as testing if problems emerge.

A central element of human-centered design is that designers should address the issues in Fig. 1 in the same order that stakeholders address these issues. Thus, the *last* concern is, "Does it run?" The *first* concern is, "What matters?" or "What constitutes benefits and costs?"

Viability. Are the benefits of system use sufficiently greater than the costs? While this question cannot be answered empirically prior to having a design, one can determine how the question is likely to be answered. How do stakeholders characterize benefits? Are they looking for speed, throughput, an easier job, or appealing surroundings? What influences their perceptions of these characteristics? How do stakeholders characterize costs? Is it simply purchase price? Or, do costs include the costs of maintenance and perhaps training? Are all the costs monetary?

Acceptability. Do organizations/individuals use the system? This is also a question that cannot be answered definitively prior to having the results of design. However, one can determine in advance the factors that are likely to influence the answer. Most of these factors relate to the extent to which a product or system fits into an organization's philosophy, technology, and so on.

Validity. Does the product or system solve the problem? This, of course, leads to the question, What is the problem? How would you know if the problem was solved, or not solved? The nature of this question was discussed earlier in this article.

Evaluation. Does the system meet requirements? Formulation of the design problem should result in specification of requirements that must be satisfied for a design solution to be successful. Examples include speed, accuracy, throughput, and manufacturing costs.

Demonstration. How do observers react to the system? It is very useful to get the reactions of potential stakeholders long before the product or system is ready for evaluation. It is important, however, to pursue demonstration in a way that does not create a negative first impression.

Verification. Is the system put together as planned? This question can be contrasted with a paraphrase of the validation question: Is the plan any good? Thus, verification is the process of determining that the system was built as intended, but does not include the process of assessing whether or not it is a good design.

Testing. Does the system run, compute, and so on? This is a standard engineering question. It involves issues of (a) physical measurement and instrumentation for hardware and (b) runtime inspection and debugging tools for software.

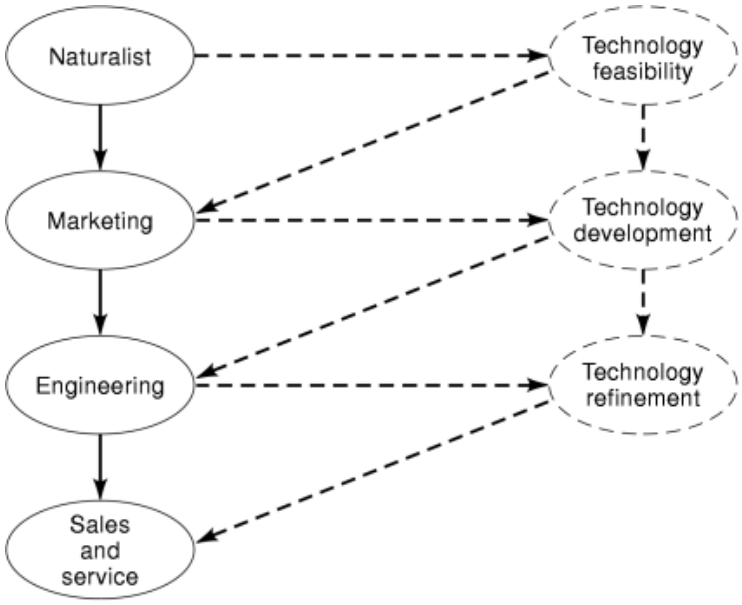

Fig. 2. A framework for measurement—four phases of the design process and the ways in which technology affects this process.

A Framework for Measurement. The discussion thus far has served to emphasize the diversity of measurement issues from the perspectives of both designers and stakeholders. If each of these issues were pursued independently, as if they were ends in themselves, the costs of measurement would be untenable. Yet, each issue is important and should not be neglected.

What is needed, therefore, is an overall approach to measurement that balances the allocation of resources among the issues of concern at each stage of design. Such an approach should also integrate intermediate measurement results in a way that provides maximal benefit to the evolution of the design product. These goals can be accomplished by viewing measurement as a process involving the four phases shown in Fig. 2.

Naturalist Phase. This phase involves understanding the domains and tasks of stakeholders from the perspective of individuals, the organization, and the environment. This understanding includes not only people's activities, but also prevalent values and attitudes relative to productivity, technology, and change in general. Evaluative assessments of interest include identification of difficult and easy aspects of tasks, barriers to and potential avenues of improvement, and the relative leverage of the various stakeholders in the organization.

Marketing Phase. Once one understands the domain and tasks of current and potential stakeholders, one is in a position to conceptualize alternative products or systems to support these people. Product concepts can be used for initial marketing in the sense of determining how users react to the concepts. Stakeholder's reactions are needed relative to validity, acceptability, and viability. In other words, one wants to determine whether or not people perceive a product concept as solving an important problem, solving it in an acceptable way, and solving it at a reasonable cost.

Engineering Phase. One now is in a position to begin tradeoffs between desired conceptual functionality and technological reality. As indicated in Fig. 2, technology development will usually have been pursued prior to and in parallel with the naturalist and marketing phases. This will have at least partially ensured that the product concepts shown to stakeholders were not technologically or economically ridiculous. However, one now

Table 1. Organization of Measurement Process

Issue/Phase	Naturalist	Marketing	Engineering	Sales and Service
Viability	Frame	Plan	Refine	Complete
Acceptability	Frame	Plan	Refine	Complete
Validity	Frame	Plan	Refine	Complete
Evaluation	–	Frame/Plan	Refine/Complete	–
Demonstration	–	Frame/Plan	Refine/Complete	–
Verification	–	Frame/Plan	Refine/Complete	–
Testing	–	Frame/Plan	Refine/Complete	–

must be very specific about how desired functionality is to be provided, what performance is possible, and the time and dollars necessary to provide it.

Sales and Service Phase. As this phase begins, the product should have successfully been tested, verified, demonstrated, and evaluated. From a measurement point of view, the focus is now on validity, acceptability, and viability. It is also at this point that one ensures that implementation conditions are consistent with the assumptions underlying the design basis of the product or system.

The Role of Technology. It is important to note the role of technology in the human-centered design process. As depicted in Fig. 2, technology is pursued in parallel with the four phases of the design process. In fact, technology feasibility, development, and refinement usually consume the lion's share of the resources in a product or system design effort. However, technology should not drive the design process. Human-centered design objectives should drive the process, and technology should support these objectives.

Organization for Measurement. Table 1 illustrates how the seven measurement issues should be organized, or sequenced, in the four phases. *Framing* an issue denotes the process of determining what an issue means within a particular context and defining the variables to be measured. *Planning* is concerned with devising a sequence of steps and schedule for making measurements. *Refining* involves using initial results to modify the plan, or perhaps even rethink issues and variables. Finally, *completing* is the process of making outcome measurements and interpreting results.

Table 1 provides a useful context in which to discuss typical measurement problems. There are two classes of problems of interest. The first class is *planning too late* where, for example, failure to plan for assessing acceptance can preclude measurement prior to putting a product into use. The second class of problems is *executing too early* where, for instance, demonstrations are executed prior to resolving test and verification issues and potentially lead to negative initial impressions of a product or system.

Naturalist Phase

The purpose of the naturalist phase is gaining an understanding of stakeholders' domains and tasks. This includes assessing the roles of individuals, their organizations, and the environment. Also of interest is identifying barriers to change and avenues for change.

Table 2. Methods and Tools for the Naturalist Phase

Methods and Tools	Purpose	Advantages	Disadvantages
Magazines and newspapers	Determine customers' and users' interests via articles and advertisements.	Use is very easy and inexpensive.	Basis and representativeness of information may not be clear.
Databases	Access demographic, product, and sales information.	Coverge is both broad and quantitative.	Available data may only roughly match information needs.
Questionnaires	Query large number of people regarding habits, needs, and preferences.	Large population can be inexpensively queried.	Low return rates and shallow nature of responses.
Interviews	In-depth querying of small number of people regarding activities, organization, and environment.	Face-to-face contact allows in-depth and candid interchange.	Difficulty of gaining access, as well as time required to schedule and conduct.
Experts	Access domain, technology, and/or methodological expertise.	Quickly able to come up to speed on topics.	Cost of use and possible inhibition on creating in-house expertise.

The result of the naturalist phase is a formal description of stakeholders, their tasks, and their needs. This description can take many forms, ranging from text to graphics and ranging from straightforward descriptions to theories and hypotheses regarding stakeholders' behaviors.

This section elaborates and illustrates the process of developing descriptions of stakeholders, tasks, and needs. The descriptions resulting from the naturalist phase are the starting point for the marketing phase.

Identifying Stakeholders. Who are the stakeholders? This is *the* central question with which a human-centered design effort should be initiated. The answer to this question is *not* sufficient for success. However, the answer to this question is certainly necessary.

Stakeholder Populations. The key issue is identifying a set of people whose tasks, abilities, limitations, attitudes, and values are representative of the total population of interest. It is often necessary to sample multiple organizations to gain this understanding of the overall population. An exception to the guideline occurs when the total population of stakeholders resides in a single organization.

Designers as Stakeholder Surrogates. Rather than explicitly identifying stakeholders, it is common for designers to think, perhaps only tacitly, that they understand stakeholders and, therefore, can act as their surrogates. To the extent that designers are former stakeholders, this approach has some merit. However, it is inherently limited from capturing the abilities, attitudes, and aspirations of current or potential stakeholders, as well as the current or potential impact of their organizations.

Elusive Stakeholders. It is often argued, particularly for advanced technology efforts, that the eventual stakeholders for the product or system of interest do not yet exist—there are no incumbent stakeholders. This is very seldom true because there are actually extremely few products and systems that are designed "from scratch." Even, for example, when designing the initial spacecraft, much was drawn from previous experiences in aircraft and submarines.

Methods and Tools for Measurement. How does one identify stakeholders and, in particular, how does one determine their needs, preferences, values, and so on? Observation is, of course, the necessary means. Initially, unstructured direct observations may be appropriate. Eventually, however, more formal means should be employed to ensure unbiased, convincing results. Table 2 lists the methods and tools appropriate for answering these types of questions.

Magazines and Newspapers. To gain an initial perspective on what is important to a particular class of stakeholders or a particular industry, one should read what they read. Trade magazines and industry

newspapers publish what interests their readers. One can capitalize on publishers' insights and knowledge by studying articles for issues and concerns. For example, is cost or performance more important? Is risk assessment, or equivalent, mentioned frequently?

One should pay particular attention to advertisements, because advertisers invest heavily in trying to understand customers' needs, worries, and preferences. One can capitalize on advertisers' investments by studying the underlying messages and appeal in advertisements.

It is useful to create a file of articles, advertisements, brochures, catalogs, and so on, that appear to characterize the stakeholders of interest. The contents of this file can be slowly accumulated over a period of many months before it is needed. This accumulation might be initiated in light of long-term plans to move in new directions. When these long-term plans become short-term plans, this file can be accessed, the various items juxtaposed, and an initial impression formed relatively quickly.

Databases. There are many relatively inexpensive sources of information about stakeholders available via online databases. With these sources, a wide variety of questions can be answered. How large is the population of stakeholders? How are they distributed, organizationally and geographically? What is the size of their incomes? How do they spend it?

Such databases are also likely to have information on the companies whose advertisements were identified in magazines and newspapers. What are their sales and profits? What are the patterns of growth?

By pursing these questions, one may be able to find characteristics of the advertisements of interest that discriminate good versus poor sales growth and profits. Such characteristics might include leading-edge technology, low cost, and/or good service.

Questionnaires. Once magazines, newspapers, and databases are exhausted as sources of information, attention should shift to seeking more specific and targeted information. An inexpensive approach is to mail, or otherwise distribute, questionnaires to potential stakeholders to assess how they spend their time, what they perceive as their needs and preferences, and what factors influence their decisions.

Questions should be brief, have easily understandable responses, and be straightforward to answer. Multiple choice questions or answers in terms of rating scales are much easier to answer than open-ended, essay-like questions, even though the latter may provide more information.

Low return rate can be a problem with questionnaires. Incentives can help. For example, those who respond can be promised a complete set of the results. In one effort, an excellent response rate was obtained when a few randomly selected respondents were given tickets to Disney World.

Results with questionnaires can sometimes be frustrating. Not infrequently, analysis of the results leads to new questions which one wishes had been on the original questionnaire. These new questions can, however, provide the basis of a follow-up agenda.

Interviews. Talking with stakeholders directly is a rich source of information. This can be accomplished via telephone, but face-to-face is much better. The use of two interviewers can be invaluable to enable one person to maintain eye contact and the other to take notes. The use of two interviewers also later provides two interpretations of what was said.

Usually, interviewees thoroughly enjoy talking about their jobs and what types of products and systems would be useful. Often, one is surprised by the degree of candor people exhibit. Consequently, interviewees usually do not like their comments tape-recorded.

It is helpful if interviewees have first filled out questionnaires, which can provide structure to the interview as they explain and discuss their answers. Questionnaires also ensure that they will have thought about the issues of concern prior to the interview. In the absence of a prior questionnaire, the interview should be carefully structured to avoid unproductive tangents. This structure should be explained to interviewees prior to beginning the interview.

Experts. People with specialized expertise in the domain of interest, the technology, and/or the market niche can be quite valuable. People who were formerly stakeholders within the population of interest tend to

be particularly useful. These people can be accessed via the Internet or informal telephone calls (which are surprisingly successful), gathered together in invited workshops, and/or hired as consultants.

While experts' knowledge can be essential, it is very important that the limitations of experts be realized. Contrary to the demeanor of many experts, very few experts know everything! Listen and filter carefully.

Furthermore, it is very unlikely that one expert can cover a wide range of needs. Consider multiple experts. This is not due to a need to get a good average opinion. It is due to the necessity to cover multiple domains of knowledge.

Summary. The success of all of the above methods and tools depends on one particular ability of designers—the ability to *listen*. During the naturalist phase, the goal is understanding stakeholders rather than convincing them of the merits of particular ideas or the cleverness of the designers. Designers will get plenty of time to talk and expound in later phases of the design process. At this point, however, success depends on listening.

Marketing Phase

The purpose of the marketing phase is introducing product *concepts* to potential customers, users, and other stakeholders. In addition, the purpose of this phase includes planning for measurements of viability, acceptability, and validity. Furthermore, initial measurements should be made to test plans, as opposed to the product, to uncover any problems before proceeding.

It is important to keep in mind that the product and system concepts developed in this phase are primarily for the purpose of addressing viability, acceptability, and validity. Beyond that which is sufficient to serve this purpose, minimal engineering effort should be invested in these concepts. Beyond preserving resources, this minimalist approach avoids, or at least lessens, "ego investments" in concepts prior to knowing whether or not the concepts will be perceived to be viable, acceptable, and valid.

These types of problem can also be avoided by pursuing more than one product concept. Potential stakeholders can be asked to react to these multiple concepts in terms of whether or not each product concept is perceived as solving an important problem, solving it in an acceptable way, and solving it at a reasonable cost. Each person queried can react to all concepts, or the population of potential stakeholders can be partitioned into multiple groups, with each group only reacting to one concept.

The marketing phase results in an assessment of the relative merits of the multiple product concepts that have emerged up to this point. Also derived is a preview of any particular difficulties that are likely to later emerge. Concepts can be modified, both technically and in terms of presentation and packaging, to decrease the likelihood of these problems.

Methods and Tools for Measurement. How does one measure the perceptions of stakeholders relative to the viability, acceptability, and validity of alternative product and system concepts? Table 3 lists the appropriate methods and tools for answering this question, as well as their advantages and disadvantages.

Questionnaires. This method can be used to obtain the reactions of a large number of stakeholders to alternative functions and features of a product or system concept. Typically, people are asked to rate the desirability and perceived feasibility of functions and features using, for example, scales of 1 to 10. Alternatively, people can be asked to rank order functions and features.

As noted when questionnaires were discussed earlier, low return rate can be a problem. Furthermore, one typically cannot have respondents clarify their answers, unless telephone or in-person follow-ups are pursued. This tends to be quite difficult when the sample population is large.

Questionnaires can present problems if they are the only methods employed in the marketing phase. The difficulty is that responses may not discriminate among functions and features. For example, respondees may rate as 10 the desirability of all functions and features.

Table 3. Methods and Tools for the Marketing Phase

Methods and Tools	Purpose	Advantages	Disadvantages
Questionnaires	Query large number of people regarding preferences for product's functions.	Large population can be inexpensively queried.	Low return rates and shallow nature of responses.
Interviews	In-depth querying of small number of people regarding reactions to and likely use of product's functions.	Face-to-face contact allows in-depth exploration of nature and perceptions of product's functions and benefits.	Difficulty of gaining access, as well as time required to schedule and conduct.
Scenarios	Provide feeling for using product in terms of how functions would likely be used.	Inexpensive approach to providing rich impression of product's functions and benefits.	Written scenarios are not as compelling as visual presentation and require users' willingness to read.
Mock-ups	Provide visual look and feel of product.	Strong visual image can be created and reinforced with photographs.	Necessarily emphasize surface features which are not always product's strength.
Prototypes	Provide ability to use product, typically in a fairly limited sense.	Very powerful and compelling approach to involving potential users.	Relatively expensive and not fully portable; sometimes lead to inflated expectations.

This sounds great—one has discovered exactly what people want! However, an alternative interpretation is that the alternatives were not sufficiently understood for people to perceive different levels of desirability among the alternatives. Asking people to rank order items can eliminate this problem, at least on the surface. However, questionnaires usually are not sufficiently rich to provide people with real feelings for the functionality of the product or system.

Interviews. Interviews are a good way to follow-up questionnaires, perhaps for a subset of the population sampled if the sample was large. As noted earlier, questionnaires are a good precursor to interviews in that they cause interviewees to have organized their thoughts prior to the interviews. In-person interviews are more useful than telephone interviews because it is much easier to iteratively uncover perceptions and preferences during face-to-face interaction.

Interviews are a good means for determining people's a priori perceptions of the functionality envisioned for the product or system. It is useful to assess these a priori perceptions independently of the perceptions that one may subsequently attempt to create. This assessment is important because it can provide an early warning of any natural tendencies of potential stakeholders to perceive things in ways other than intended in the new product or system. If problems are apparent, one may decide to change the presentation or packaging of the product to avoid misperceptions.

Scenarios. At some point, one has to move beyond the list of words and phrases that describe the functions and features envisioned for the product or system. An interesting way to move in this direction is by using stories or scenarios that embody the functionality of interest and depict how these functions might be utilized.

These stories and scenarios can be accompanied by a questionnaire within which respondents are asked to rate the realism of the depiction. Furthermore, they can be asked to explicitly consider, and perhaps rate, the validity, acceptability, and viability of the product functionality illustrated. It is not necessary, however, to explicitly use the words "validity," "acceptability," and "viability" in the questionnaire. Words should be chosen that are appropriate for the domain being studied; for example, viability may be an issue of cost in some domains and not in others.

It is very useful to follow-up these questionnaires with interviews to clarify respondents' comments and ratings. Often the explanations and clarifications are more interesting and valuable than the ratings.

Mock-Ups. Mock-ups are particularly useful when the form and appearance of a product or system are central to stakeholders' perceptions. For products such as automobiles and furniture, form and appearance are obviously central. However, mockups can also be useful products and systems where appearance does not seem to be crucial.

For example, computer-based systems obviously tend to look quite similar. The only degree of freedom is what is on the display. One can exploit this degree of freedom by producing mockups of displays using photographs or even viewgraphs for use with an overhead projector.

One word of caution, however. Even such low-budget presentations can produce lasting impressions. One should make sure that the impression created is such that one wants it to last. Otherwise, as noted earlier, one may not get an opportunity to make a second impression.

Prototypes. Prototypes are a very popular approach and, depending on the level of functionality provided, can give stakeholders hands-on experience with the product or system. For computer-based products, rapid prototyping methods and tools have become quite popular because these methods and tools enable the creation of a functioning prototype in a matter of hours.

Thus, prototyping has two important advantages. Prototypes can be created rapidly and enable hands-on interaction. With these advantages, however, come two important disadvantages.

One disadvantage is the tendency to produce ad hoc prototypes, typically with the motivation of having something to show stakeholders. It is very important that the purpose of the prototype be kept in mind. It is a device with which to obtain initial measurements of validity, acceptability, and viability. Thus, one should make sure that the functions and features depicted are those for which these measurements are needed. One should not, therefore, put something on a display simply because it is intuitively appealing. This can be a difficult impulse to avoid.

The second disadvantage is the tendency to become attached to one's prototypes. At first, a prototype is merely a device for measurement, to be discarded after the appropriate measurements are made. However, once the prototype is operational, there is a tendency for people, including the creators of the prototype, to begin to think that the prototype is actually very close to what the final product or system should be like. In such situations, it is common to hear someone say, "Maybe with just a few small changes here and there . . .."

Prototypes can be very important. However, one must keep their purpose in mind and avoid "rabid" prototyping! Also, care must be taken to avoid premature ego investments in prototypes. The framework for design presented in this article can provide the means for avoiding these pitfalls.

Summary. During the naturalist phase, the goal was to listen. In the marketing phase, one can move beyond just listening. Various methods and tools can be used to (a) test hypotheses that emerged from the naturalist phase and (b) obtain potential stakeholders' reactions to initial product and system concepts.

Beyond presenting hypotheses and concepts, one also obtains initial measurements of validity, acceptability, and viability. These measurements are in terms of quantitative ratings and rankings of functions and features, as well as more free flow comments and dialogue.

Engineering Phase

The purpose of the engineering phase is developing a final design of the product or system. Much of the effort in this phase involves using various design methods and tools in the process of evolving a conceptual design to a final design. In addition to synthesis of a final design, planning and execution of measurements associated with evaluation, demonstration, verification, and testing are pursued.

Four-Step Process. In this section a four-step process for directing the activities of the engineering phase and documenting the results of these activities is discussed. The essence of this process is a structured approach to producing a series of design documents. Beyond the value of this approach to creating a human-centered design, documentation produced in this manner can be particularly valuable for tracing back from

design decisions to the requirements and objectives that motivated the decisions. For example, suggested design changes are much easier to evaluate and integrate into an existing design when one can efficiently determine why the existing design is as it is.

It is important to note that the results of the naturalist and marketing phases should provide a strong head start on this documentation process. In particular, much of the objectives document can be based on the results of these phases. Furthermore, and equally important, the naturalist and marketing phases will have identified the stakeholders in the design effort and are likely to have initiated relationships with many of them.

Objectives Document. The first step in the process is developing the Objectives Document. This document contains three attributes of the product or system to be designed: goals, functions, and objectives.

Goals are characteristics of the product or system that designers, users, and customers would like the product or system to have. Goals are often philosopical choices, frequently very qualitative in nature. There are usually multiple ways of achieving goals. Goals are particularly useful for providing guidance for later choices.

Functions define what the product or system should do, but not how it should be done. Consequently, there are usually multiple ways to provide each function. The definition of functions subsequently leads to analysis of objectives.

Objectives define the activities that must be accomplished by the product or system in order to provide functions. Each function has at least one, and often five to ten, objectives associated with it. Objectives are typically phrased as imperative sentences beginning with a verb.

There are two purposes for writing a formal document listing goals, functions, and objectives. First, as noted earlier, written documents provide an audit trail from initial analyses to the "as-built" product or system. The Objectives Document provides the foundation for all subsequent documents in the audit trail for the engineering phase. The second purpose of the Objectives Document is that it provides the framework—in fact, the outline—for the Requirements Document.

All stakeholders should be involved in the development of the Objectives Document. This includes at least one representative from each type of stakeholder group. This is important because this document defines what the eventual product or system will and will not do. All subsequent development assumes that the functions and objectives in the Objectives Document form a necessary and complete set.

The contents of the Objectives Document can be based on interviews with subject-matter experts, including operators, maintainers, managers, and trainers. Baseline and analogous systems can also be valuable, particularly for determining objectives that have proven to be necessary for providing specific functions.

Much of the needed information will have emerged from the marketing phase. At the very least, one should have learned from the marketing phase what questions to ask and who to ask. All the stakeholders in the process should have been identified and their views and preferences assessed.

The level of detail in the Objectives Document should be such that generality is emphasized and specifics are avoided. The activities and resulting document should concentrate on what is desirable. Discussion of constraints should be delayed—budgets, schedules, people, and technology can be considered later.

Requirements Document. Once all the stakeholders agree that the Objectives Document accurately describes the desired functions and objectives for the product or system, the next step is to develop the Requirements Document. The purpose of this document is to identify all information and control requirements associated with each objective in the Objectives Document.

For evolutionary designs, baseline and analogous systems can be studied to determine requirements. However, if the product or system being designed has no antecedent, subject-matter expertise can be very difficult to find. In this case, answers to the above questions have to come from engineering analysis and, if necessary, validated empirically.

The Requirements Document should be reviewed and approved by all stakeholders in the design effort. This approval should occur prior to beginning development of the conceptual design. This document can also be very useful for determining the functional significance of future design changes. In fact, the Requirements

Document is often used to answer downstream questions that arise concerning why particular system features exist at all.

Conceptual Design Document. The conceptual design of a product or system should accommodate *all* information and control requirements as parsimoniously as feasible within the state of the art. The conceptual design, as embodied in the Conceptual Design Document, is the first step in defining *how* the final system will meet the requirements of the Requirements Document. The Conceptual Design Document should describe a complete, workable system that meets all design objectives.

Realistically, one should expect considerable disagreement as the conceptual design evolves. However, the Conceptual Design Document should not reflect these disagreements. Instead, this document should be iteratively revised until a consensus is reached. At that point, all stakeholders should agree that the resulting conceptual design is a desirable and appropriate product or system.

Detailed Design Document. The fourth and final step in the design process involves synthesizing a detailed design. Associated with the detailed design is the Detailed Design Document. This document describes the "production" version of the product or system, including block diagrams, engineering drawings, parts lists, and manufacturing processes.

The Detailed Design Document links elements of the detailed design to the functionality within the Conceptual Design Document, which are in turn linked to the information and control requirements in the Requirements Document, which are in turn linked to the objectives within the Objectives Document. These linkages provide powerful means for efficiently revising the design when, as is quite often the case, one or more stakeholders in the design process do not like the implications of their earlier choices. With the audit trail provided by the four-step design process, evaluating and integrating changes are much more straightforward. As a result, good changes are readily and appropriately incorporated, and bad changes are expeditiously rejected.

Summary. In this section the engineering phase has been described in terms of a documentation process, including the relationships among documents. Obviously, much of the engineering phase concerns creating the contents of these documents. Many of the other articles in this encyclopedia provide detailed guidance on these engineering activities.

Sales and Service Phase

Initiation of the sales and service phase signals the accomplishment of several important objectives. The product or system will have been successfully tested, verified, demonstrated, and evaluated. In addition, the issues of viability, acceptability, and validity will have been framed, measurements planned, and initial measurements executed. These initial measurements, beyond the framing and planning, will have exerted a strong influence on the nature of the product or system.

Sales and Service Issues. In this phase, one is in a position to gain closure on viability, acceptability, and validity. One can make the measurements necessary for determining if the product or system really solves the problem that motivated the design effort, solves it in an acceptable way, and provides benefits that are greater than the costs of acquisition and use. This is accomplished using the measurement plan that was framed in the naturalist phase, developed in the marketing phase, and refined in the engineering phase.

These measurements should be performed even if the product or system is "pre-sold"—for example, when a design effort is the consequence of a winning proposal. In this case, even though the "purchase" is ensured, one should pursue closure on viability, acceptability, and validity in order to gain future projects.

There are several other activities in this phase beyond measurement. One should ensure that the implementation conditions for the product or system are consistent with the assumed conditions upon which the design is based. This is also the point at which the later steps of stakeholder acceptance plans are executed,

Table 4. Methods and Tools for the Sales and Service Phase

Methods and Tools	Purpose	Advantages	Disadvantages
Sales reports	Assess perceived viability of product or system.	The ultimate, bottom-line measure of success.	Information on lack of sales due to problems is likely to be too late to help.
Service reports	Assess typical problems and impact of solutions attempted.	Associate problems with customers and users and enable follow-up.	May be too late for major problems and may not explain cause.
Questionnaires	Query large number of customers and users regarding experiences with product.	Large population can be inexpensively queried.	Low return rates and shallow nature of responses.
Interviews	In-depth querying of small number of customers and users regarding experiences with product.	Face-to-face contact allows in-depth and candid interchange.	Difficulty of gaining access, as well as time required to schedule and conduct.

typically with a broader set of people than those who participated in the early steps of the plan. This phase also often involves technology-transition considerations in general.

The sales and service phase is also where problems are identified and remediated. To the greatest extent possible, designers should work with stakeholders to understand the nature of problems and alternative solutions. Some problems may provide new opportunities rather than indicating shortcomings of the current product or system. It is important to recognize when problems go beyond the scope of the original design effort. The emphasis then becomes one of identifying mechanisms for defining and initiating new design efforts to address these problems.

The sales and service phase also provides an excellent means for maintaining relationships. One can identify changing stakeholders that occur because of promotions, retirements, resignations, and reorganizations. Furthermore, one can lay the groundwork and make initial progress on the naturalist phase, and perhaps the marketing phase, for the next project, product, or system.

Methods and Tools for Measurement. How does one make the final assessments of viability, acceptability, and validity? Furthermore, how does one recognize new opportunities? Unstructured direct observation can provide important information. However, more formal methods are likely to yield more definitive results and insights. Table 4 lists the methods and tools appropriate for answering these types of questions.

Sales Reports. Sales are an excellent measure of success and a good indicator of high viability, acceptability, and validity. However, sales reports are a poor way of discovering a major design inadequacy. Furthermore, when a major problem is detected in this manner, it is quite likely that one may not know what the problem is or why it occurred.

Service Reports. Service reports can be designed, and service personnel trained, to provide much more than simply a record of service activities. Additional information of interest concerns the specific nature of problems, their likely causes, and how stakeholders perceive and react to the problems. Stakeholders' suggestions for how to avoid or solve the problems can also be invaluable. Individuals' names, addresses, and telephone numbers can also be recorded so that they subsequently can be contacted.

Questionnaires. Questionnaires can be quite useful for discovering problems that are not sufficient to prompt service calls. They also can be useful for uncovering problems with the service itself. If a record is maintained of all stakeholders, this population can regularly be sampled and queried regarding problems, as well as ideas for solutions, product upgrades, and so on. As noted before, however, a primary disadvantage of questionnaires is the typical low return rate.

Interviews. Interviews can be a rich source of information. Stakeholders can be queried in depth regarding their experiences with the product or system, what they would like to see changed, and new products and

systems they would like. This can also be an opportunity to learn how their organizations make purchasing decisions, both in terms of decision criteria and budget cycles.

While sales representatives and service personnel can potentially perform interviews, there is great value in having designers venture out to the sites where their products and systems are used. Such sorties should have clear measurement goals, questions to be answered, an interview protocol, and so on, much in the way that is described in earlier sections.

Summary. The sales and service phase brings the measurement process full circle. An important aspect of this phase is using the above tools and methods to initiate the next iteration of naturalist and marketing phases. To this end, as was emphasized earlier, a primary prerequisite at this point is the ability to *listen*.

Conclusions

This article has presented a framework for human-centered design. Use of this framework will ensure a successful product or system in terms of viability, acceptability, validity, and so on. In this way, human-centered design provides the basis for translating technology opportunities into market innovations.

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WILLIAM B. ROUSE
Enterprise Support Systems