



SCIENCE PROFESSIONALS

MASTER'S EDUCATION FOR A COMPETITIVE WORLD



NATIONAL RESEARCH COUNCIL
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SCIENCE PROFESSIONALS

MASTER'S EDUCATION FOR A COMPETITIVE WORLD

Committee on Enhancing the Master's Degree in the Natural Sciences

Board on Higher Education and Workforce

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Preface

This study examines the role of master's education in the natural sciences¹ and whether and how master's degree programs might be enhanced to bolster our nation's workforce and our science-based industries. To carry out the study, the National Academies appointed a committee of experts that was charged with exploring and answering, as possible given the data available, the following questions:

1. What are employer needs for staff trained in the natural sciences at the master's degree level? Are they able to find or develop the staff they need at this level? How do employers communicate their employment needs to educational programs and how can this communication be enhanced?

2. How do master's-level professionals in the natural sciences contribute in the workplace? What are the employee characteristics that employers seek in staff with advanced training? Do master's-level professionals enter the workforce with a master's degree or do they enter with a bachelor's degree and earn a master's degree later?

3. What is known about students who pursue and obtain master's degrees in the natural sciences? What are their educational and career goals? How do master's programs meet or support these educational and career goals?

¹By natural sciences, we mean the physical sciences, biological sciences, geosciences, mathematics, and computer science.

4. What can be learned from efforts already under way to reshape master's education in science? What effective practices have been identified that could be adopted by others?

5. What can master's-level programs in the natural sciences learn from each other? What can they learn from the way graduate-level professional programs in fields such as business, public policy, public health, and engineering developed to meet employer needs?

6. What findings and conclusions about appropriate goals and effective practices for enhancing master's education in the natural sciences can be drawn from the answers to the preceding questions?

7. What recommended next steps can the committee provide for stakeholders—students, faculty, department chairs, university administrators, employers, federal agencies and policymaking bodies—concerned with enhancing master's-level professional education?

As a result of its work in carrying out this charge, the committee determined that there is a strong employer need for graduates of professional science master's programs and, moreover, that these graduates would make a significant contribution to our national competitiveness and security through their employment in a variety of science-based positions in industry, government, and nonprofits. Consequently, this report, while covering each of the questions in the charge, tended to focus more heavily on questions about employer needs, student characteristics and the ways that graduates can contribute in the workplace, and what can be learned from efforts under way to enhance the master's in the natural sciences, particularly as a professional degree. The questions regarding communication between employers and institutions is important and addressed, but one that requires new research and we make a recommendation regarding this. Question five was addressed, but examined primarily in Appendix F, with only brief discussion in the report.

This report, then, was organized to present a focused argument, particularly about professional science master's programs. For the reader interested in specific questions in the charge, the following provides pointers to places where they are addressed:

1a. What are employer needs for staff trained in the natural sciences at the master's degree level and how do they communicate their needs? Demands of the marketplace are addressed on pages 31-32; emerging employer needs on pages 39-44 and Boxes 2-6 and 2-7; and a general discussion of evidence for employer demand on pages 44-46 and Appendix I.

1b. How do employers communicate their employment needs to educational programs and how can this communication be enhanced?

Employers tend to communicate their needs in two ways: (1) at the local level, where they may be engaged in employer advisory boards, and (2) through national associations. Like others working in this area, we believe—and have recommended—that strong connections between programs and advisory boards, if properly constituted and energized, can provide an important link here. See particularly pages 50-51 and the recommendations 6 and 7, pages 65-68.

2. How do master's-level professionals in the natural sciences contribute in the workplace? What are the employee characteristics that employers seek in staff with advanced training? The answer to these questions can be found in those that address the questions about employer needs. See pages 40-44.

3. What is known about students who pursue and obtain master's degrees in the natural sciences? The report addressed the numbers of master's degrees awarded annually by field on pages 17-21; student goals on pages 23-26, 32-33, and Box 2-1; careers of graduates on pages 26-29; and offers and salaries of recent graduates on pages 44-46.

4. What can be learned from efforts already under way to reshape master's education in science? What effective practices have been identified that could be adopted by others? This has been extensively covered in the report. See pages 33-40 and 46-52, and Boxes 2-3, 2-4, and 2-5.

5. What can be learned from the development of other professional degree programs? This is covered on pages 21-23 and more extensively in Appendix F.

The committee was comprised of individuals who brought expertise in the natural sciences disciplines, graduate education, higher education administration, and employer needs in industry, government, and non-profits. To cover the broad range of employers, the committee included members who have experience in each of these areas. James Spohrer, Philip Tuchinsky, Rita Colwell, and Henry Riggs work or have worked in industry and bring experience from such diverse sectors as information technology, biotechnology, automotive manufacture, and business analytics. Rita Colwell, Donald Langenberg, Mary Clutter, Daryl Chubin, and Paul Gaffney are all former federal officials who bring experience with federal science agencies and, in the case of Vice Admiral Gaffney, the defense establishment as well. Jonathan Kayes is the current Chief Learning Officer with the Central Intelligence Agency. Daryl Chubin, Lee Huntsman, and Thomas Tritton are all currently affiliated with nonprofit science organizations. (See Committee member biographies in Appendix B for further details.)

The committee gathered evidence in several ways to address its charge:

- Experts in competitiveness, graduate education, and industry workforce needs testified to the committee at its meetings in March and July 2007;
- Representatives of innovative master’s degree programs in the natural sciences presented descriptions of those programs to the committee at its March and July meetings;
- Officials of the Alfred P. Sloan Foundation, the National Science Foundation (NSF), and the Council of Graduate Schools provided the committee with their perspectives on master’s education, particularly in the context of all graduate education and U.S. economic competitiveness;
- The committee reviewed and assessed the provisions of Section 7034 of the America COMPETES Act²—passed by the U.S. Congress and signed into law by President George W. Bush during the course of this study—that authorizes the NSF to develop a program of grants for the creation or expansion of professional science master’s degree programs; and
- Staff conducted a review of the relevant literature and data.

The committee synthesized this information as a foundation for this report and its findings and conclusions. It drew on these data and information to the extent they were already available and it drew as well on the experience, expertise, views and collective judgment of the committee members. As described in detail in Chapter 2, projecting demand for a “product,” especially a relatively new one like the professional science master’s degree, is fraught with particular difficulty even when such data as offers and salary comparisons support one’s conclusions. It is the judgment of this committee, nonetheless, that PSM graduates are in demand and will continue to be in increasing numbers in the future. (Meeting agendas in Appendix C list individuals who spoke to the committee. The full text of Section 7034 of the America COMPETES Act is provided in Appendix D.)

One audience for this report includes Congress, the president and the administration, the federal agencies charged with carrying out the America COMPETES Act, and educational and science policymakers at the state level. We would also like to note the importance of the philanthropic community both in promoting innovation in higher education generally and in driving change in master’s education in the sciences more specifically. The Alfred P. Sloan Foundation and the William M. Keck Foundation have played important roles in the last decade in laying the foundation for change. We believe there is an ongoing role for philan-

²America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, Public Law No. 110-69.

thropy in encouraging continued development in master's education and we address this audience as well.

The audience for the report also encompasses four-year institutions of higher education, students, and employers—all of whom are actors in the development of professional science education. Higher education institutions need to innovate to continue to offer programs that are relevant to society and the economy. While this report urges change in master's education, we expect that these changes will also impact undergraduate-level and doctoral-level education. We urge students to take advantage of the opportunities provided by new and exciting programs, like the professional science master's that is described in this report, that provide not only a more advanced understanding of science but also practical skills for the workplace. Employers—industry, nonprofits, and government—are critical to the success of this initiative. They should form partnerships with master's degree programs to develop and evolve curricula on an ongoing basis and provide mentoring, internships, team projects, and employment.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this report: Robert Atkinson, Information Technology and Innovation Foundation; G. Wayne Clough, Georgia Institute of Technology; T. Gregory Dewey, Keck Graduate Institute of the Applied Life Sciences; Judith Glazer-Raymo, Columbia University; Susan Hackwood, California Council on Science and Technology; Karen Klomparens, Michigan State University; Carol Nacy, Sequella, Inc.; Stephanie O'Sullivan, Central Intelligence Agency; Linda Strausbaugh, University of Connecticut; William Valdez, Department of Energy; Bogdan Vernescu, Worcester Polytechnic Institute; and Ernst Volgenau, SRA International.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Charles Phelps, University of Rochester. Appointed by the National Academies, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures

and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The study committee thanks the Alfred P. Sloan Foundation for the financial support it provided for this study and the many experts who met with the committee to provide their insights on the policy context, employers' workforce needs, and developments in master's education. We also thank the staff of the National Academies who helped organize our committee meetings and draft the report.

Rita R. Colwell, *Chair*
Committee on Enhancing the
Master's Degree in the Natural Sciences

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Summary

In the course of our nation's history, our leadership has made bold moves to equip our people with the skills and knowledge needed for the future. The Morrill Land Grant Act of 1862, the Serviceman's Readjustment Act of 1944 (commonly known as the GI Bill), and the National Defense Education Act of 1958, each reflecting the needs of its times, spurred social, economic, and technological change through undergraduate and graduate education.

There is growing consensus that we are again at one of those moments when we need bold actions. The vitality and competitiveness of the U.S. economy is due in large measure to the investment our nation has made over five decades in research and higher education, yielding a steady stream of scientific and technical innovations. Many countries, however, now invest in research and the development of knowledgeable people who play a critical role in competitive success. The development of research capacity and productivity in Europe and Asia and the global competition for talent are now challenging U.S. technological leadership.

There has not been a singular event, such as the Soviet launch of Sputnik in October 1957, to sound a clarion call to action. Instead, the situation has developed under the radar like a "Silent Sputnik." It is a situation of deep concern nonetheless and the nation needs to act.

Americans concerned about the nation's position in the global economy have provided recommendations to fuel the competitiveness of both our economy and the scientific enterprise: steps needed to improve K-12 science and mathematics education; make the United States the most

attractive setting in which to study and conduct research; sustain and strengthen the nation's commitment to long-term basic research that secures our country; and ensure that the United States is the premier place in the world to promote innovation. Last summer, the U.S. Congress passed and the president signed into law the America COMPETES Act laying the groundwork for the implementation of many of these recommendations. Yet more, including the necessary appropriation of funds for new or expanded programs, is needed.

Talent is one of the important keys to innovation and competitive success. Reforming K-12 science, technology, engineering, and mathematics education and encouraging undergraduates to pursue technical education and careers are both critical. Supporting doctoral students who will undertake future research is fundamental. Yet, the master's-trained segment of the science workforce is pivotal: strengthened master's education in the natural sciences will prepare professionals who bring scientific knowledge and also the ability to anticipate, adapt, learn, and lead where and when needed in industry, government, and nonprofits.

Traditionally, the master's degree in the natural sciences has tended to be single-discipline in orientation, an extension of undergraduate science education, and preparatory to the doctorate. In many fields, such as the biological sciences, physics, and chemistry, the award of a master's degree has typically signified either a "stepping-stone" en route to the doctorate or a "consolation prize" for those who were not admitted to candidacy or dropped out. Exciting experiments in master's education over the last decade—the Master of Biosciences (MBS) program at the Keck Graduate Institute of Applied Life Sciences and the Professional Science Master's (PSM) initiative seeded by the Alfred P. Sloan Foundation¹—have shown that graduate education in these fields can prepare students for advanced science-based work in a way that is highly desired by employers. These programs are useful and scalable.

In the COMPETES Act, the 110th Congress agreed, authorizing the National Science Foundation (NSF) to create a new program of grants to four-year institutions that will provide for the creation or expansion of PSM programs. Through this authorization, Congress acknowledged the role in our economy and government at this point in history of the professional who possesses a balanced breadth and depth of scientific knowledge and practical workplace skills for the productive and innova-

¹While the MBS and PSM degree programs represent different institutional approaches to effecting change in professional science master's education (see Boxes 2-3 and 2-4 in Chapter 2), they are similar in goals, curricular approaches, and their interaction with employers. For purposes of this report, findings, conclusions, and recommendations regarding the PSM should be seen as including the MBS as well.

tive application of that knowledge—that is, a new kind of scientist with multidisciplinary skills and experiences.

The time is now right to accelerate and spread nationally the development of this new concept—professional science master’s education that is interdisciplinary in character, strongly emphasizes effective communication and problem solving, and provides an understanding of entrepreneurial skills and technical innovation. Successful programs that have responded to this challenge have engaged collaboratively a broad set of stakeholders—employers, prospective students, faculty, government agencies, and other funders—in designing curricula, defining education projects and internships, and advocating this new educational opportunity.

These programs do not displace classical master’s programs. Rather, faculty develop them to serve the needs of students who require a different graduate experience for the workplace: banks, insurance and financial companies, and large firms who hire graduates of PSM programs in financial and industrial mathematics; a maturing biotechnology industry with a growing need for middle managers who have both advanced scientific knowledge and broader business skills; services corporations like IBM that require employees with depth in science and breadth in business and customer skills; and government employers (particularly in the military, intelligence, and homeland security agencies) that have an increasing need for science- and technology-savvy staff, particularly those with an interdisciplinary background.

FINDINGS

After extensive information gathering and deliberation, we recommend concerted action to accelerate the development nationally of professional science master’s education. This recommendation is based on the following findings:

1. In the natural sciences, the master’s degree is as varied in its purpose as it is in any broad field. Master’s degrees in fields such as physics, chemistry, the biological sciences, and mathematics have typically signified either a “stepping stone” en route to the doctorate or a “consolation prize” for those who were not admitted to candidacy or dropped out. Master’s degrees in computer science and the geosciences, by contrast, have typically prepared graduates for the workplace. In the early part of the 20th century, professional and graduate education took divergent paths and physics, chemistry, and biology are exemplars of classical graduate education. Professional degrees, by contrast, served as credentials for practice. During the last 50 years, tremendous growth in master’s

degrees awarded in fields such as education and business administration, however, has indicated the professionalization of master's education. This trend has recently touched natural sciences such as the biological sciences and mathematics where traditional master's programs continue—as they should—alongside the recent development of professional science master's programs.

2. Higher education institutions are responding to the increased need for professionals who bring both scientific knowledge and professional skills to the workplace by developing professional science master's programs in the natural sciences that provide:

- Advanced education in the sciences;
- Opportunities for more interdisciplinary training, often in informatics, computation, or engineering, than a typical science degree;
- Hands-on experiential learning through internships and team projects;
- Professional skills and experience in communication, teamwork, project management, business administration, innovation and commercialization, legal and regulatory issues, ethics, and/or the international environment; and
- Strong links with employers in industry, government, and nonprofits through external advisory boards, curriculum development, internships/co-ops, mentoring, sponsored team projects, and employment.

Examples of PSM programs that were presented to the committee showed that professional master's education in the sciences can provide tailored, cost-effective, and attractive education and training to meet student and employer needs.

3. Professional master's programs can and do attract students who want to work in nonacademic sectors, interdisciplinary careers, team-oriented environments, managerial or other professional-level positions, or emerging areas of science and scientific discovery. They appeal to students who typically do not pursue doctoral education, but seek career advancement, look to gain a competitive edge, or want to refine professional and technical skills in order to reenter the workforce.

4. Salary and placement data for PSM and MBS graduates indicates strong and growing current demand for master's-level science professionals. Testimony to the committee provided specific examples of the demand for these graduates from biotechnology companies, banks and financial corporations, information technology firms, and government agencies. There is, moreover, broad support for expanding PSM education, voiced by the President's Council of Advisors on Science and Technology, the National Science Board, the National Governors Association, the Council

on Competitiveness, the U.S. Chamber of Commerce, the Association of American Universities, and the Council of Graduate Schools. We cannot, of course, precisely project future demand as many factors influence labor markets at any particular point in time. Our experience as employers and educators, however, leads us to believe that the current strong demand will continue to grow in the long run and that the nation will benefit from the development of a cadre of science-educated professionals. The graduates of PSM and MBS programs will become process managers, service scientists, investment analysts, patent examiners, science and technology acquisition managers, forensic scientists, or other types of professional scientists. From among these, in the judgment of this committee, some number will also emerge as leaders, executives, and in industry, government, and non-profit organizations.

5. Our review of the evolution of professional programs in other fields revealed the important role of foundations in shaping both the content and growth of programs in medicine, business, public health, and other areas. Foundation support—from the William M. Keck Foundation and the Alfred P. Sloan Foundation—has been critical as well in the development of professional master’s programs in the sciences. In the committee’s judgment, future funding and support for professional master’s programs should be a responsibility shared by the federal government, state governments, philanthropic organizations, employers, and higher education institutions.

RECOMMENDATIONS

In August 2007, Congress passed the America COMPETES Act, which authorizes the NSF to develop and implement a program of grants to higher education institutions that may use them to develop or expand PSM degree programs. We see this as a step along the road toward growing a large cadre of science-trained professionals in the United States, though the program is authorized but not yet funded. Yet stakeholders—notably the federal government, state governments, philanthropic institutions, national associations, higher education institutions, employers, and students—must undertake additional steps in order to secure the long-run success of our nation’s efforts to address this important workforce need.

1. To achieve specific national goals as well as meet general demand for science-trained professionals, we recommend the **federal government** expand the PSM program authorized in the COMPETES Act so that it is

the responsibility of the NSF and all other major federal science agencies² as well. We recommend that each agency program include two components: (1) a program of institutional PSM grants competitively awarded to four-year higher education institutions for the establishment and start-up operations of PSM programs and (2) a program of National Innovation Scholarships that provides need-based scholarships for U.S. citizens who will use them to pay for tuition and expenses when they enroll in PSM programs. It is critical that Congress appropriate funds for this multi-agency program beginning in fiscal year 2009 and at an appropriate level. If this program flourishes and demand for PSM graduates increases as much as the committee expects it will, then program funding will need to be considerably larger than the levels that Congress has so far authorized.

2. **State governments**, which have a long history of efforts in economic development, should regard PSM degree programs as critical to producing a cadre of science professionals who can play an important role in managing and growing science- and technology-based industries in their states. Along with the federal government, states should provide funding for the creation and expansion of these programs to target particular state and regional needs.

3. **Philanthropic institutions** should continue to play a role in creating and sustaining PSM degree programs and otherwise spurring innovation in master's education. Foundations can provide matching funds for federal grants, funding to assist students with financial aid, and the seed money for the establishment of a base of new programs in a specific field or in support of a specific industry.

4. Each **professional society** in the natural sciences and **industry association** in high-technology or science-based industries should develop an overall strategy for addressing higher education in its field that includes the PSM and specific actions to help create and sustain PSM programs and other innovations.

5. **Higher education institutions** should continue to innovate in and support the development of master's degree programs in the natural sciences to meet the needs of students seeking science-based careers and of the employers who hire them. PSM programs will provide students with deeper, often interdisciplinary, scientific knowledge and must include opportunities for the development of professional skills and practice

²The major federal science agencies are those that have the largest shares of federal research and development spending and together comprise more than 90 percent of such spending. These include, in addition to the NSF, the Departments of Defense, Energy, Health and Human Services (National Institutes of Health), Commerce (National Institute of Standards and Technology and National Oceanic and Atmospheric Administration), Agriculture, Interior, and Homeland Security, and the National Aeronautics and Space Administration.

through courses, summer internships, and business- or government-sponsored projects that provide an invaluable workplace experience. Providing incentives to and support for faculty to participate in these efforts, including program design and implementation, is critical.

6. **Higher education institutions** should reach out to and work as partners with employers to create and sustain programs. The use of external employer advisory councils will provide substantive, real-time input for framing of new science master's programs and practical assistance with curriculum development, mentoring, marketing, employer-sponsored projects, internships, hiring for graduates, and financial support. Institutions should also provide outreach to students, informing undergraduate students and potential graduate students of the PSM degree opportunity.

7. **Employers** in the for-profit, nonprofit, and government sectors should partner with higher education institutions to create and sustain PSM programs. They should participate on employer advisory councils through which they can assist with and benefit from program conception, curriculum development, mentoring, employer-sponsored projects, internships, employment, and financial support. They should invite representatives of PSM programs to speak at local or regional business gatherings that provide a forum for communication about the existence and attributes of PSM programs and their graduates. We encourage employers to broaden their recruiting beyond traditional sources to hire graduates from new programs. This includes not only federal agencies that require Ph.D.s for their world-class research centers, but also procurement officers, acquisition officials, project and program managers, and senior executives who, in their investment decision-making roles, must understand the latest in technology while simultaneously ensuring competitive business management outcomes. The PSM provides an outstanding model for educating the individuals who can fill these important federal career positions.

8. **Students** in PSM degree programs should take full advantage of internships and industry-sponsored team projects. We encourage alumni to provide the professional programs from which they graduated with links to and resources from their current employers who can assist with mentoring, internship opportunities, and information about employment.

1

Innovation

INNOVATION AND COMPETITIVENESS

The United States enjoys a vital, dynamic economy that is the largest national economy in the world. The vitality of that economy, as the National Academies' report *Rising Above the Gathering Storm* eloquently conveys, "is derived in large part from the productivity of well-trained people and the steady stream of scientific and technical innovations they produce."¹ Over the last decade, however, Americans have engaged in critical discussions about the nation's position in the global economy and the steps necessary to sustain the competitiveness of both our economy and the scientific enterprise that fuels its growth in the long run. (See Box 1-1.)

The disquiet about our competitiveness has found its voice among journalists and business leaders. Tom Friedman writes of a "flattened world" in which the economic playing field has been leveled through revolutionary forces—among them knowledge workers deployed throughout the world and networked through the creation of a global telecommunications system. Andy Grove, former CEO of Intel, contends: "If the world operates as one big market, every employee will compete with every person anywhere in the world who is capable of doing the same job. There are lots of them and many of them are hungry." The Council on Competitiveness, under the banner of "Innovate or Abdicat[e]," advo-

¹National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, DC: The National Academies Press, 2007), 1.

Box 1-1
The Context for Innovation and Competitiveness Policy

The United States takes deserved pride in the vitality of its economy, which forms the foundations of our high quality of life, our national security, and our hope that our children and grandchildren will inherit ever greater opportunities. That vitality is derived in large part from the productivity of well-trained people and the steady stream of scientific and technical innovations they produce. Without high-quality, knowledge-intensive jobs and the innovative enterprises that lead to discovery and new technology, our economy will suffer and our people will face a lower standard of living. Economic studies conducted even before the information-technology revolution have shown that as much as 85 percent of measured growth in U.S. income per capita was due to technological change.

Today, Americans are feeling the gradual and subtle effects of globalization that challenge the economic and strategic leadership that the United States has enjoyed since World War II. A substantial portion of our workforce finds itself in direct competition for jobs with lower wage workers around the globe, and leading-edge scientific and engineering work is being accomplished in many parts of the world. Thanks to globalization, driven by modern communications and other advances, workers in virtually every sector must now face competitors who live just a mouse-click away in Ireland, Finland, China, India, or dozens of other nations whose economies are growing. This has been aptly referred to as “the Death of Distance.”

Having reviewed trends in the United States and abroad, the committee is deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength.... Although the U.S. economy is doing well today, current trends indicate...that the United States may not fare as well in the future without government intervention. This nation must prepare with great urgency to preserve its strategic and economic security. Because other nations have, and probably will continue to have, the competitive advantage of a low wage structure, the United States must compete by optimizing its knowledge-based resources, particularly in science and technology, and by sustaining the most fertile environment for new and revitalized industries and the well-paying jobs they bring.

—Excerpted from NAS/NAE/IOM's, *Rising Above the Gathering Storm: Energizing and Employing Americans for a Brighter Economic Future* (Washington, DC: The National Academies Press, 2007), 1-4.

cates a national effort to spur innovation as the intensification of a global knowledge economy has put pressure on the United States to remain a step ahead of the competition and ensure the United States is the premier place in the world to innovate.²

²Thomas L. Friedman, *The World Is Flat: A Brief History of the 21st Century* (New York: Farrar, Giroux, and Strauss, 2005). See also Andrew S. Grove, *High Output Management*

In May 2005, senators Lamar Alexander (R-Tennessee) and Jeff Bingaman (D-New Mexico) asked the National Academies to respond to the question “What are the top 10 actions, in priority order, that federal policymakers could take to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century?” The Academies acted quickly to produce *Rising Above the Gathering Storm*, a report that provides recommendations for action to improve K-12 science and mathematics education; to make the United States the most attractive setting in which to study and perform research; to sustain and strengthen the nation’s commitment to long-term basic research that fuels the economy and secures our country; and to ensure that the United States is the premier place in the world to promote innovation.

Rising Above the Gathering Storm and the administration’s subsequent American Competitiveness Initiative, along with the recently passed America COMPETES Act,³ have placed innovation and competitiveness among the nation’s highest policy priorities. The visibility and momentum of the competitiveness agenda provide an opportunity to shed light on each of the components of the U.S. science and engineering enterprise to ensure that they will contribute all they can and must in order to achieve our national goals. One of those components is the education and training of a science, technology, engineering, and mathematics (STEM) workforce that brings advanced scientific and technical knowledge, along with key business skills, to innovation in our private and public sectors. Our focus here, then, is on ensuring that our institutions of higher learning provide high-quality postsecondary and graduate education, including master’s education, that meets students’ and employers’ needs.

INVESTING IN THE KNOWLEDGE WORKFORCE

Many countries in addition to the United States now emphasize the important role that knowledgeable and creative people play in any competitive field and therefore, by extension, the critical role of higher education in competitiveness. Ireland transformed itself from a relatively impoverished European nation into a technology hub with a gross domestic product among the highest in the European Union. It did so through

(New York: Vintage Books, 1995), and Council on Competitiveness, *Innovate America*, <http://innovateamerica.org/> (accessed October 20, 2007). The council’s calls for action and recommendations have been echoed and amplified by such organizations as the Association of American Universities in *National Defense Education and Innovation Initiative: Meeting America’s Economic and Security Challenges in the 21st Century*. This report can be found at <http://www.aau.edu/reports/NDEII.pdf> (accessed October 20, 2007).

³America Creating Opportunities, *ibid*.

tax policy, incentives for foreign investment, and a substantial investment in the education of its people.⁴ The European Commission now urges its member states to increase the number of STEM graduates and argues that “investment in learning . . . [is] more critical than ever in the context of a ‘knowledge based society’. . . it pays off for all concerned—the state, the employer and the individual.” The European Union considers education to be a key part of its drive to achieve the goals outlined in the Lisbon Strategy “to become the most competitive and dynamic knowledge-based economy in the world.”⁵ Similarly, India and China are taking steps to increase and enhance STEM education and to enlarge their workforces in these areas.⁶ To compete, then, the United States must pursue a two-pronged course: first, to invest in research at the leading edge and find new ways to convert that knowledge to use; and second, to stay ahead of the competition in the development of its science and engineering workforce.

Rising Above the Gathering Storm provided compelling recommendations for sustaining and increasing our knowledge workforce:⁷

- Annually recruit 10,000 science and mathematics teachers through scholarships and strengthen the skills of 250,000 teachers through training and education programs;
- Enlarge the pipeline of students who are prepared to enter college and graduate with a STEM degree by increasing the number of students who pass advanced placement and international baccalaureate science and mathematics courses;
- Increase the number and proportion of U.S. citizens who earn bachelor’s degrees in the physical sciences, life sciences, engineering, and mathematics by providing 25,000 new four-year undergraduate scholarships each year;
- Increase the number of U.S. citizens who pursue graduate study in areas of national need by funding 5,000 new graduate fellowships each year;
- Provide federal incentives for continuing education in STEM fields; and

⁴NAS/NAE/IOM, *Rising Above the Gathering Storm*, 199.

⁵http://ec.europa.eu/growthandjobs/areas/fiche10_en.htm (accessed October 19, 2007).
http://europa.eu/scadplus/glossary/education_en.htm (accessed October 20, 2007).

⁶In *India and the Knowledge Economy: Leveraging Strengths and Opportunities*, a report that emerged from high-level interactions with policymakers in India, the World Bank urged India to broaden participation in science, engineering, information technology, and research. See <http://info.worldbank.org/etools/docs/library/138271/IndiaKEExecutiveSummary%5B1%5D.pdf> (accessed January 30, 2008).

⁷NAS/NAE/IOM, *Rising Above the Gathering Storm*, 5-7, 9-10.

- Continue to improve visa processing and immigration systems to ensure that international students and scholars have access to our educational institutions and research.

In passing the America COMPETES Act, Congress laid the groundwork for the implementation of many of these recommendations if and when program funds are appropriated.

The act added to the list of important steps in several key ways. For example, it asked the National Academies to identify actions to increase the participation of underrepresented minorities in STEM fields, because the full participation of all our nation's talented individuals in science and engineering is critical to our competitiveness. It also authorized the National Science Foundation (NSF) to create a new program of grants to four-year institutions that will provide for the creation or expansion of professional science master's (PSM) programs. PSM programs offer our nation an opportunity to provide not just more advanced scientists, but a new kind of scientist with multidisciplinary skills and experiences.⁸ Through the authorization of a PSM program at the NSF, Congress acknowledged the importance to our economy and government at this point in history of a type of professional who possesses an advanced knowledge of science, a deeper understanding of business or management, and a range of practical workplace skills that allow for the productive and innovative application of that knowledge.

Science—and its application in the workplace—has itself generated changes in and even enabled or created new fields and industries. Advances in computing power and storage capacity have created whole new fields, such as business intelligence and bioinformatics. Business intelligence, which uses advanced mathematics in analyzing large data sets to inform business strategy, only now exists as a field because of recent developments in mass data storage, which in turn exist because of research on giant magnetoresistance that led to phenomenal growth in data storage capacity over the last two decades. Similarly, bioinformatics provides an example of a field that emerged in the same period of time through the productive interaction of two disciplines—computer science and biology—to contribute to such important scientific endeavors as genomic research. A third example, biotechnology has developed in the

⁸Michael S. Teitelbaum, "A New Science Degree to Meet Industry Needs," *Issues in Science and Technology*, Fall 2006. Sheila Tobias and Leslie B. Sims, "Training Science and Mathematics Professional for an Innovation Economy," *Industry and Higher Education*, August 2006. Christopher T. Hill, "The Post-Scientific Society," *Issues in Science and Technology*, Fall 2007, 78–84. See also Council of Graduate Schools, "Graduate Education: The Backbone of American Competitiveness and Innovation, 2007"; this report can be found at http://www.cgsnet.org/portals/0/pdf/GR_GradEdAmComp_0407.pdf (accessed October 20, 2007).

latter decades of the 20th century by applying advances in the life sciences to the development of new treatments for disease.

In each of these cases, a new discipline or industry unknown just two decades ago has emerged, and in these areas professionals trained at the master's level in the sciences may be key contributors and innovators in the workplace. Biotechnology and other science-based industries, such as computer services, require people who can bring advanced scientific knowledge along with a broader set of skills that allow for the productive exchange and implementation of that knowledge in the workplace. Master's degree programs are able to provide students with the opportunity to obtain advanced science knowledge beyond the baccalaureate and can also incorporate opportunities for students to obtain, through class work or project experience and internships, the ability to communicate well, work in teams, and other skills. Industry needs what some have referred to as the "T-shaped" professional: individuals with depth and breadth. They have "contributory knowledge" (deep learning in the science) as well as "interactional/articulatory expertise" (breadth of workplace skills). Organizations whose staff are not only knowledgeable but are able to share that knowledge effectively are positioned for greater success.⁹

REFORM IN GRADUATE EDUCATION

Advocates for reform in graduate education have voiced the need for new types of programs since the mid-1990s. In *Reshaping the Graduate Education of Scientists and Engineers*, the National Academies' Committee on Science, Engineering, and Public Policy found that more than half of new Ph.D.s in the sciences and engineering were pursuing careers outside of academia. That study recommended that, in addition to providing a solid grounding in science, doctoral programs should incorporate into their curricula opportunities for graduate students to obtain important skills—for example, communication skills—that would enhance their work in nonacademic settings.¹⁰ Several subsequent efforts to reenvision or reform doctoral education have also urged that programs include opportunities for acquiring a broad range of skills.¹¹

⁹Marcelo Cataldo, Kathleen M. Carley, and Linda Argote, "The Effect of Personnel Schemes on Knowledge Transfer," found at <http://www.casos.cs.cmu.edu/events/conferences/2000/pdf/Marcelo-Cataldo.pdf> (accessed December 11, 2007).

¹⁰NAS/NAE/IOM, *Reshaping the Graduate Education of Scientists and Engineers* (Washington, DC: National Academy Press, 1995).

¹¹ Carnegie Initiative on the Doctorate, <http://www.carnegiefoundation.org/programs/index.asp?key=29>. Re-envisioning the Ph.D., <http://www.grad.washington.edu/envision/resources/studies.html>. Woodrow Wilson National Fellowship Foundation: The Responsive Ph.D., <http://www.woodrow.org/responsivephd/> (accessed January 28, 2008).

The NSF also took action to help spur this innovation in graduate education by establishing the Integrative Graduate Education and Research Traineeship (IGERT) program in 1997. The goal of the IGERT program is to catalyze a culture change in graduate education to equip U.S. science and engineering graduate students to address the challenges of the 21st century by engaging in research that crosses disciplinary, departmental, or even institutional boundaries and provides student trainees with deep knowledge in a field while learning the skills needed to work as part of an interdisciplinary team. Two years later, the NSF created the Graduate Teaching Fellows in K-12 Education program (GK-12) program to link the K-12 sciences and mathematics community to the research communities and provide funding to graduate students in NSF-supported STEM disciplines so that they may acquire, through interactions with teachers and students in K-12 schools, additional skills that will broadly prepare them for professional and scientific careers. Both IGERT and GK-12 expand the skills and capabilities of the traditional Ph.D. recipient. (See Box 1-2.)

There have been important experiments in master's education in the natural sciences—experiments that laid the groundwork for such action as the congressional authorization of a PSM program through the America COMPETES Act. Our survey of the role of the master's degree across disciplines within science and without shows a lack of clarity as to the meaning of the degree and the skills/knowledge/capability it denotes to the recipient. This mystifies students and employers alike and represents a lost opportunity: for science-educated baccalaureates to continue along a science pathway; for the nation, which requires highly educated and skilled innovators. It is to master's education, including such experiments as the PSM, that we turn in the next chapter. The PSM represents an antidote to the lost opportunity; one that reflects both employer needs (the demand side) and university flexibility and creativity (as a supplier of trained talent).

Box 1-2
Reform in Graduate Education: IGERT and GK-12

Since 1997 the NSF has supported a training program called the Integrative Graduate Education and Research Traineeship (IGERT) (www.nsf.gov/crssprgm/igert/intro.jsp) whose goal is to equip U.S. science and engineering graduate students with in-depth knowledge in a disciplinary field while learning the skills needed to work as part of an interdisciplinary team. Their training involves courses and other activities that will provide them with a working knowledge of science, business, technical, social, ethical, and policy issues. They have the opportunity to pursue their research with internships in industry, government labs, foreign institutions, or other academic sites where they can engage in collaborative activities. Awards are made on a competitive basis to institutions that propose an interdisciplinary research project involving a diverse group of faculty members and students crossing disciplinary, departmental, or even institutional boundaries. The awards are made as five-year grants to academic institutions. The project must include strategies for recruitment, mentoring, and retention of members of groups underrepresented in science and engineering.

Another NSF program, Graduate Teaching Fellows in K-12 Education (GK-12) (www.nsfgk12.org), provides funding to graduate students in science, technology, engineering, and mathematics (STEM) disciplines to acquire additional skills that will broadly prepare them for professional and scientific careers in the 21st century. NSF developed the GK-12 program in recognition that STEM graduate students, in addition to being competent researchers, must be able to communicate science and research to a variety of audiences. As the GK-12 Fellows bring their research and practice into the K-12 classroom, they gain skills in explaining science to people of all ages. By working in K-12 formal and informal learning environments, the Fellows not only stimulate interest in science and engineering among students and teachers, but also apply interdisciplinary thinking and demonstrate the close connection between education and research. Since its inception in 1999, the GK-12 program has funded over 200 projects in more than 140 different universities throughout the United States and Puerto Rico.

Master's Education

THE LANDSCAPE OF MASTER'S EDUCATION

Students increasingly find master's education a valuable pursuit. As measured by the number of degrees awarded, education at the master's level is growing faster than other sectors of postsecondary education in the United States. Higher education institutions awarded 230,509 master's degrees in 1970-1971. By 2004-2005, they awarded 574,618, an increase of almost 150 percent. As shown in Table 2-1, this rate of growth was more than double that for bachelor's degrees and research doctorates during the same time period. Since 1980, the rate of growth in master's degrees awarded has also been significantly higher than for professional degrees in law, medicine, and dentistry.¹

The professional disciplines of education and business dominate the master's degree programs in the United States. Together they grant 54 percent of all master's degrees. As shown in Table 2-2 (and Appendix H, Table H-1), these fields—along with health sciences, engineering, public administration and social services professions, psychology, and computer and information sciences—comprise 80 percent of all master's degrees awarded in 2004-2005. With the exception of education, these fields are also among the fastest growing at this level. Other fields with higher than average growth, as shown in Figure 2-1, include physical education/exercise science, criminal justice/security and protective services, legal

¹<http://nces.ed.gov/programs/coe/2007/section5/table.asp?tableID=741> (accessed October 21, 2007).

TABLE 2-1 Bachelor's, Master's, and Doctoral Degrees Conferred and Percent Change over Time, Selected Years, 1970-1971 to 2004-2005

| Year | Bachelor's | Master's | Doctorates |
|---|------------|----------|------------|
| 1970-1971 | 839,730 | 230,509 | 32,107 |
| 1975-1976 | 925,746 | 311,771 | 34,064 |
| 1980-1981 | 935,140 | 295,739 | 32,958 |
| 1985-1986 | 987,823 | 288,567 | 33,653 |
| 1990-1991 | 1,094,538 | 337,168 | 39,294 |
| 1995-1996 | 1,164,792 | 406,301 | 44,652 |
| 2000-2001 | 1,244,171 | 468,476 | 44,904 |
| 2001-2002 | 1,291,900 | 482,118 | 44,160 |
| 2002-2003 | 1,348,503 | 512,645 | 46,024 |
| 2003-2004 | 1,399,542 | 558,940 | 48,378 |
| 2004-2005 | 1,439,264 | 574,618 | 52,631 |
| Percent change, 1970-1971 to 2004-2005 | 71% | 149% | 64% |
| Percent change, 1995-1996 to 2004-2005 | 24% | 41% | 18% |

SOURCE: U.S. Department of Education, National Center for Education Statistics, Higher Education General Information Survey, "Degrees and Other Formal Awards Conferred," surveys 1970-1971 through 1985-1986 and 1990-1991 through 2004-2005; and Integrated Postsecondary Education Data System, "Completions Survey" (C: 91-99), Fall 2000 through Fall 2005. (See Digest of Education Statistics, 2006, Table 257, http://nces.ed.gov/programs/digest/d06/tables/dt06_257.asp, accessed October 22, 2007.)

research and studies, and a catchall field, multidisciplinary and interdisciplinary studies. With the exception of computer science, the numbers of master's degrees awarded in natural sciences fields are both small and slow growing. Master's degrees awarded in the biological sciences grew 27 percent from 1975-1976 to 2004-2005. The number in the mathematics and the physical sciences grew just 16 and 5 percent, respectively, during this 30-year period.

Though career-oriented fields now dominate master's degree programs, this has not always been the case. In Judith Glazer-Raymo's words, "Throughout its long history, the master's degree has been variously characterized by graduate faculty and deans as an intermediate degree,

TABLE 2-2 Master's Degrees Conferred, by Field, 2004-2005

| Field | Number | Percentage |
|---|---------|------------|
| Education | 167,490 | 29 |
| Business, management, marketing, and personal and culinary services | 142,617 | 25 |
| Health professions and related clinical sciences | 46,703 | 8 |
| Engineering and engineering technologies | 35,133 | 6 |
| Public administration and social service professions | 29,552 | 5 |
| Psychology | 18,830 | 3 |
| Computer and information sciences and support services | 18,416 | 3 |
| Biological sciences, physical sciences, and mathematics | 18,354 | 3 |
| Social sciences, psychology, and history | 16,952 | 3 |
| Other | 80,571 | 14 |
| Total | 574,618 | 100 |

SOURCE: U.S. Department of Education, National Center for Education Statistics, 2004-05 Integrated Postsecondary Education Data System (IPEDS), Fall 2005. (See Digest of Education Statistics, 2006, Table 258, http://nces.ed.gov/programs/digest/d06/tables/dt06_258.asp, accessed October 22, 2007.)

signifying its location following the baccalaureate and preceding the doctorate, as a 'predoctoral' or 'intermediate' year of graduate school or stepping-stone to the doctorate."² Indeed, graduate education that prepares students for the doctorate and professional education that prepares students for practice in law and medicine took divergent paths in the first half of the 20th century. The award of a master's degree in the context of doctoral education signified either a "stepping-stone" en route to the doctorate or a "consolation prize" for those who were not admitted to candidacy or who dropped out. Professional degrees, by contrast, served as credentials for practice.

The surge in the number of master's degrees awarded in the second half of the 20th century was generated by increases in education, business, and other professionally oriented fields. Indeed, one important thrust of

²Judith Glazer-Raymo, *Professionalizing Graduate Education: The Master's Degree in the Marketplace* (ASHE Higher Education Report, Vol. 31, No. 4, 2005), 1.

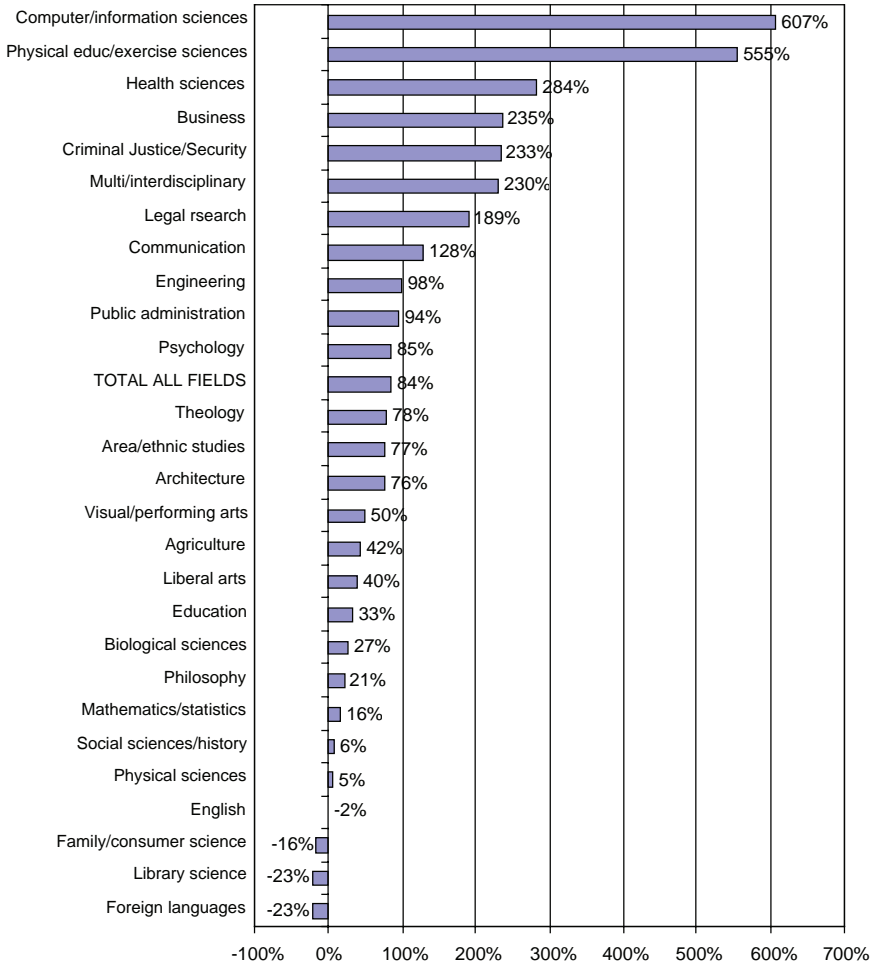


FIGURE 2-1 Percentage of change in number of master’s degrees awarded by discipline, 1975-1976 to 2004-2005.

SOURCE: U.S. Department of Education, National Center for Education Statistics, 2004-2005 Integrated Postsecondary Education Data System (IPEDS), Fall 2005. (See Digest of Education Statistics, 2006, Table 258, http://nces.ed.gov/programs/digest/d06/tables/dt06_258.asp, accessed October 22, 2007.)

change in the last several decades has been toward the professionalization of master's education.³

So, the master's degree now means different things to different stakeholders and has a varied purpose across fields. To some, this has seemed a source of confusion or even chaos. To others, this ability to mean different things to different people in varied settings is the key to its "silent success" as a degree⁴ and its ability to be responsive to the changing needs of both students and society. "Students pursue master's degrees," writes the Council of Graduate Schools, "to prepare for further advanced study or for entry into public school or community college teaching, to improve and upgrade their professional skills, to change professional fields, and to explore their own personal intellectual development."⁵

Many factors have spurred this change in master's education. Primary factors have been the need for students to obtain sufficient knowledge in an area of practice and to acquire an awareness of professional standards in order to gain access to and recognition in a profession. Professional and master's education in business, public administration, and public health developed to meet these needs in response to the demands of the marketplace as institutions adapted to important changes in our society, economy, or government. (See Appendix F.) The development of the master of business administration (MBA) is illustrative. In 1881, the Wharton School at the University of Pennsylvania became the first institution to offer such a degree, but the MBA degree did not immediately take off. Only in the 20th century did it grow in popularity in response to employers' need for staff who could apply scientific methods to management and labor as American industry matured. Only after World War II did pressure from accreditors and foundations lead to graduate rather than undergraduate business schools. Business school curricula have evolved over the last century with the development of new management approaches: quality control in the 1920s; operations research and cybernetics by the 1950s; total quality management in the 1980s; and reengineering in the 1990s—all further responses to industry change.⁶

The development of professional education in public administration and public health has followed similar trajectories, and in these fields the master's degree supplanted the bachelor's as the credential for entry

³As the award of so many master's degrees in what are, for most recipients, areas of professional practice, Judith Glazer-Raymo suggests that for many, professional and master's education are re-converging. *Ibid.*, 16.

⁴Clifton Conrad, Jennifer Grant Haworth, and Susan Bolyard Millar, *A Silent Success: Master's Education in the United States* (Baltimore: Johns Hopkins University Press, 1993).

⁵Council of Graduate Schools, *Professional Master's Education: A CGS Guide to Establishing Programs* (Washington, DC: Council of Graduate Schools, 2006), ix.

⁶Glazer-Raymo, *Professionalizing Graduate Education*. Conrad et al., *A Silent Success*.

Box 2-1 Master's Education for Science and Mathematics Teachers

The most frequently awarded master's degrees in the United States are in education, with nearly 170,000 in the 2004-2005 academic year. Teachers' salaries are generally strongly linked to degrees earned and courses taken, as well as time in service. Education master's programs are therefore important factors in the teacher professional development enterprises that are ubiquitous in state and local elementary and secondary education systems. In her book *Professionalizing Graduate Education*, Judith Glazer-Raymo asserts, "The master's degree is a pivotal step toward professionalization of teaching." Though that assertion is consistent with the position our committee has taken here with respect to non-research careers in the sciences, the master's degree in education does not fall within our charge. (Another NRC committee, The Committee on the Study of Teacher Preparation Programs in the United States, will issue a report addressing this issue within several months of our committee's report.) Nevertheless, we would suggest that attention be given to the development of professional science master's degree programs designed specifically for science teachers. Like other aspects of our K-12 educational systems, education master's programs have become the focus of increasing attention and concerns about their quality, coherence, and performance accountability. To help address the issue of teacher quality in science and mathematics education, *Rising Above the Gathering Storm* recommends providing grants to research universities to offer, over five years, 50,000 current middle and high school science, mathematics, and technology teachers two-year part-time master's degree programs that focus on rigorous science and mathematics content and pedagogy. The report offers as a model for the action the University of Pennsylvania Science Teacher Institute. In addition to the natural science content, we offer that such programs could also focus on exploring the growing body of research-based knowledge of optimal pedagogical techniques in the teaching of science.

SOURCE: Judith Glazer-Raymo, *Professionalizing Graduate Education: The Master's Degree in the Marketplace* (ASHE Higher Education Report, Vol. 31, No. 4, 2005), 1.

into the field. In other fields, the acquisition of a master's degree is not necessarily the entry-level professional degree, but it is often important for advancement. In elementary and secondary education, for example, teachers are typically required to obtain additional education and professional development, and their salary increases are often pegged to this continuing education and the award of a master's degree. (See Box 2-1.)

In engineering, the bachelor's degree has typically been the entry-level professional degree for most subfields, but there has been an almost continuous 130-year discussion regarding the body of knowledge necessary in order to become a "professional" engineer. Bruce Seely describes

this discussion as one that has been marked by major studies every 10 to 15 years led by a variety of stakeholders (engineering faculty, practicing engineers—as represented by the leading professional societies—and leadership of major employers of engineers). The discussions have been remarkably consistent in focusing on the content and length of the engineering curricula and the relationship of theory and practice.⁷

Of significant interest, the American Society of Civil Engineers (ASCE) has now determined that the traditional baccalaureate is insufficient preparation for professional civil engineering work. Twenty-first-century technical requirements, plus nontechnical requirements, cannot be met in four years. ASCE therefore advocates the “Baccalaureate + 30”: a baccalaureate degree plus 30 extra credits, which could be graduate school or distance education.⁸

Engineering educators have resisted the trend of other professional fields to respond to the increasing knowledge and complexity of those fields by adding to the education required to prepare for professional practice. Discussions of what the engineer of 2020 should bring to the workplace, however, now presume both increased knowledge and skills in communication, business or economics, the social sciences, cross-cultural studies, and important technologies. Adding this knowledge to a strong engineering curriculum may mean that the first professional degree will need to be the master’s rather than the baccalaureate.⁹

ROLES OF MASTER’S EDUCATION IN THE NATURAL SCIENCES

Conrad et al. created a useful typology for categorizing the diverse missions of master’s degree programs. In their scheme, master’s degrees may focus on career preparation, professional development, community service, or preparation for doctoral work. An alternative typology suggests master’s degree programs can be categorized as classical, applied, professional, or a hybrid. (See Box 2-2.)

In the natural sciences—the physical sciences, biological sciences,

⁷Bruce E. Seely, “The Other Re-engineering of Engineering Education, 1900-1965,” *Journal of Engineering Education*, July 1999. See http://findarticles.com/p/articles/mi_qa3886/is_199907/ai_n8865889/pg_1 (accessed December 12, 2007).

⁸Engineering the Future of Civil Engineering: Report of the Task Committee on the First Professional Degree to the Executive Committee, Board of Direction, American Society of Civil Engineering. See <http://www.asce.org/pdf/fpd-execsumm.pdf> (accessed October 23, 2007).

⁹National Academy of Engineering, *Engineer of 2020: Visions of Engineering in the New Century* (Washington, DC: The National Academies Press, 2004) and *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (Washington, DC: The National Academies Press, 2005).

Box 2-2 Typologies of Master's Degree Programs

In their work on the master's degree, *A Silent Success*, Clifton Conrad, Jennifer Grant Haworth, and Susan Bolyard Millar suggest master's programs could be categorized as follows:

- *Career advancement programs*: Master's programs that focus on providing the student with practical skills for well-understood career opportunities. Typical of this sort of program would be one in education or business offered by a college or university for which master's education is an institutional focus.

- *Ancillary programs*: Master's programs that are defined largely in relation to, and are typically subordinate to, doctoral programs. The master's program is frequently used as a screen for the doctoral program. The master's degree is offered as either a stepping-stone to the Ph.D. or as a consolation prize for those who do not continue. These programs are most often found in institutions that focus on research and doctoral education.

- *Apprenticeship programs*: These master's programs often coexist with doctoral programs and may even be found in research-intensive institutions. Very often, the faculty in certain fields, such as electrical engineering, believe in a strong ethic of professional preparation at the master's level and devote themselves to teaching at the master's as well as at the doctoral level.

- *Community-centered programs*: Some master's programs are focused on creating for their participants not only an arena of intellectual engagement but also a strong sense of giving to the communities in which they work. Conrad et al. provide the example of a summer master's program in English that attracts many teachers from rural and urban areas. Participants are engaged in the substance of the program, which they complete over four summers, and also use what they learn in the schools they return to.

—Adapted from Clifton Conrad, Jennifer Grant Haworth, and Susan Bolyard Millar, *A Silent Success: Master's Education in the United States* (Baltimore: The Johns Hopkins University Press, 1993).

geosciences, mathematics, and computer science—master's education is as varied in its purpose as it is in any broad field. As shown in Table 2-3 (and Appendix H, Table H-2), the ratio of master's degrees to doctorates awarded each year ranges from 20.9:1 in computer science (similar to ratios in health fields and some subfields of engineering) to as low as 1.3:1 in the biological sciences and just 1:1 in chemistry. In fields like computer science and the geosciences (a subfield of earth, atmospheric, and ocean sciences), students mainly pursue master's degrees as an intentional degree in an applied field for use in professional practice. In natural sciences fields like the biological sciences, physics, and chemistry, by

In *Professional Master's Education*, the Council of Graduate Schools offers a similar typology:

- *Classical Program*: A classical program is either a stepping-stone to the Ph.D. . . . or one with the characteristics of a classical program, whether or not described as a terminal master's (often found when the university does not have a Ph.D. program in the field).

- *Applied Program*: An applied program focuses upon application of the fundamentals of the discipline to a specific area of practice (e.g., aging studies programs within sociology). Such programs often require work entirely within or minimal work outside of the department. Some programs also may lead to a specific, focused career track, but generally do not have a direct relationship to prospective employers. . . .

- *Professional*: A professional master's degree program often includes activities and relationships that cross the boundaries between departments and between the university and employers. An active interaction with potential employers provides opportunities for skills development, experience, and contacts that are closely aligned with marketplace demand.

- *Hybrid*: In addition, there are programs with characteristics of more than one of these three categories, so it is possible to have a classical/applied mix or an applied/professional mix.

—Excerpted from Council of Graduate Schools, *Professional Master's Education: A CGS Guide to Establishing Programs* (Washington, DC: Council of Graduate Schools, 2006), 43-44.

contrast, the master's degree is more likely to represent a stepping-stone or consolation prize because doctorate-level scientists are highly sought for both academic and industry careers.

Relatively little data exist that differentiate types of masters degrees: those intended master's pursued for a job or career, those that are a milestone en route to the Ph.D., or those awarded when a student leaves a Ph.D. program. For a national cohort, we can estimate a breakdown for the 9,000 graduate students in the biological sciences who entered in 1997: 3,700 earned the master's degree and no other degree (see Figures 2-2 and 2-3); 700 earned a master's degree and an advanced degree other than the

TABLE 2-3 Ratio of Master's Degrees to Doctorates Awarded by U.S. Institutions, by Field, 2004

| Field | Ratio of Master's Degrees to Ph.D.s |
|----------------------------------|-------------------------------------|
| Health | 21.7 |
| Computer science | 20.9 |
| Social sciences | 6.7 |
| Engineering | 5.9 |
| Psychology | 4.6 |
| Mathematics | 4.0 |
| Life sciences | 1.7 |
| Agricultural science | 4.0 |
| Biological sciences | 1.3 |
| Physical sciences | 1.2 |
| Earth/Atmospheric/Ocean sciences | 2.3 |
| Physics | 1.4 |
| Chemistry | 1.0 |

SOURCE: National Science Foundation, Division of Science Resources Statistics. 2006. *Science and Engineering Degrees: 1966-2004*. Arlington, VA: January 2007.

doctorate (for instance, medicine, law, business); 2,400 earned a master's, mainly as a stepping-stone to the doctorate; and 3,600 earned only a doctorate. There are no national data sources that will allow us to tease out how many of those 3,700 who earned only a master's degree intended to do so and how many had hoped to go on to a doctorate and received the master's as a consolation prize. (See Appendix E.)

The University of Utah, however, has compiled just such data for selected fields in the natural sciences and they are likely to be reasonably illustrative of experiences across graduate schools. As seen in Table 2-4, most master's degrees awarded in geology, mathematics, and meteorology were terminal: preparation for a job. The same was true for the university's Professional Master's of Science and Technology tracks. By contrast, most master's degrees awarded in biology and chemistry were merely consolation prizes for those discontinuing doctoral study, and there was a relatively low ratio of master's degrees to doctorates awarded in those fields. Few Ph.D. recipients in biology or chemistry received a master's degree en route.¹⁰

At a national level, we do know where those who earn master's degrees in the biological sciences—whether that degree was the original intent of the graduate student or not—will end up working. As shown in

¹⁰David Chapman, Dean of the Graduate School, University of Utah, presentation to the study committee, July 14, 2007.

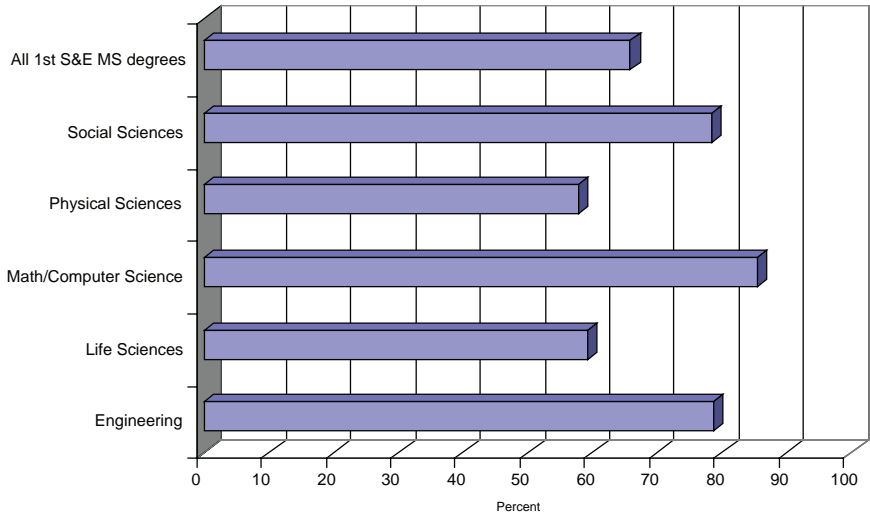


FIGURE 2-2 S&E master's degree recipient, with no additional advanced degrees 10 or more years after first S&E master's degree, by broad field, 2003 (percentage).

SOURCE: National Science Foundation (Mark Regets, presentation to committee, July 14, 2007).

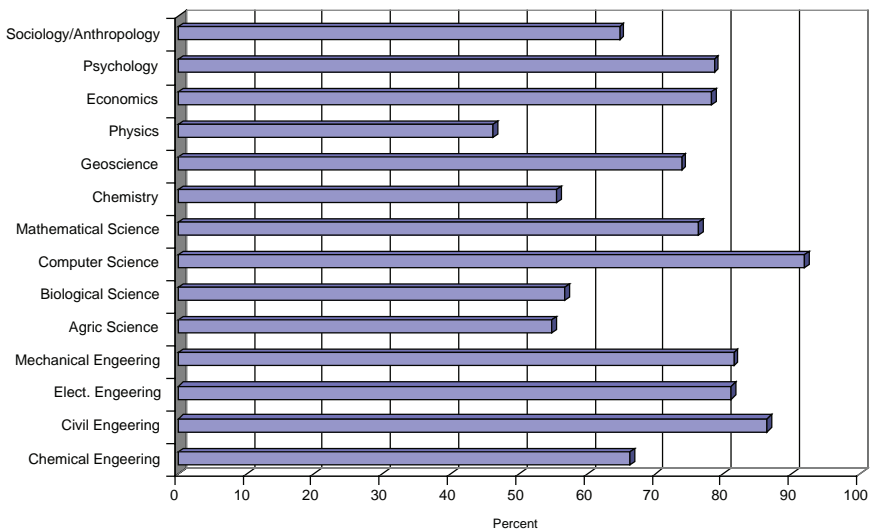


FIGURE 2-3 S&E master's degree recipient, with no additional advanced degrees 10 or more years after first S&E master's degree, by fine field, 2003 (percentage).

SOURCE: National Science Foundation (Mark Regets, presentation to committee, July 14, 2007).

TABLE 2-4 Master's Degrees Awarded by the University of Utah in Selected Natural Sciences Fields, by Type of Master's Degree and Relationship to Doctorate, 2002-2003 to 2005-2006 (four years)

| Field | Master's Degree | | MS Intended for Job | | MS when Discontinuing Ph.D. | | MS as a Milestone en route to Ph.D. | | Ph.D.s | | Number of Master's per Ph.D. |
|--------------------|-----------------|---|---------------------|-----|-----------------------------|----|-------------------------------------|----|--------|---|------------------------------|
| | # | % | # | % | # | % | # | % | # | % | |
| Biology | 15 | | 3 | 20 | 12 | 80 | 0 | 0 | 38 | | 0.4 |
| Chemistry | 51 | | 3 | 5 | 46 | 90 | 3 | 5 | 76 | | 0.7 |
| Mathematics | 93 | | 61 | 66 | 1 | 1 | 31 | 33 | 23 | | 4.0 |
| Physics | 58 | | 26 | 45 | 12 | 20 | 20 | 35 | 28 | | 2.1 |
| Geology/Geophysics | 46 | | 32 | 70 | 0 | 0 | 14 | 30 | 20 | | 2.3 |
| Meteorology | 16 | | 10 | 60 | 0 | 0 | 6 | 40 | 9 | | 1.8 |
| Professional MST | 68 | | 68 | 100 | 0 | 0 | 0 | 0 | 0 | | 0 |

SOURCE: David Chapman, Graduate Dean, University of Utah, presentation to study committee, July 14, 2007.

Table 2-5, 36 percent of those who earn master's degrees will eventually work in for-profit firms in industry; 20 percent will work in four-year colleges and universities; 17 percent will work in government; and 13 percent will work in either K-12 education or community colleges. Indeed, there are slightly more master's-level biologists employed by for-profit firms than there are doctorates. In industry, master's-educated biologists may work in research alongside Ph.D.s, but they work more frequently in other areas. One source reports that within the biotechnology workforce as a whole (not just the research segment of it), 19 percent have a Ph.D., 17 percent have a master's, 50 percent have a baccalaureate, and 14 percent have a degree from a vocational/community college.¹¹

Master's-educated biologists in the biotechnology sector work in both research and non-research areas of firms and are presumably substitutable for MBAs, JDs, or Ph.D.s in many instances. Science-educated professionals trained at the master's level who can bring particular business skills along with their scientific knowledge to the workplace may even be superior to others for certain positions—in what has been a Ph.D.-intensive industry. We would argue, then, that master's degree programs should be developed to produce individuals who have those skills.

EMERGING NEED FOR PROFESSIONAL MASTER'S IN THE NATURAL SCIENCES

The natural sciences have been “among the few academic areas that have persisted with the ‘traditional’ model of the master's degree,” according to the Council of Graduate Schools (CGS).¹² The fields of computer science, applied mathematics, and the geosciences—fields sometimes classified as engineering rather than science—are the exceptions to this generalization. In 2005 the Commission on Professionals in Science and Technology (CPST) coordinated surveys conducted by three scientific societies on master's programs as a gateway to the workforce. Data from the American Geological Institute, Society for Industrial and Applied Mathematics, and the Society for Industrial Microbiology provide a glimpse of the variations in master's education in the sciences. It is robust in the geosciences (with 122 departments and 700-plus graduates in 2004) compared to microbiology/biotechnology and applied mathematics (with about 50 programs/departments in each, but barely double digits in graduates). Applied math was seen as primarily business/industry oriented, typically not requiring a thesis but encouraging an off-campus internship. Student quality and employment placements were seen as key

¹¹Dahms (2003), cited in Judith Glazer-Raymo, *Professionalizing Graduate Education*, 54.

¹²CGS, *Professional Science Master's Education*, 4.

TABLE 2-5 Employed Individuals with Highest Degree in the Biological Sciences, by Highest Degree and Employment Sector, 2003

| Highest Degree | Total Employed | For-Profit | Self-Employed | Nonprofit | 4-Yr College/ Univ. | Other Educ. | Government |
|----------------|-------------------|------------|---------------|-----------|------------------------|-------------|------------|
| <i>Number</i> | | | | | | | |
| Bachelor's | 766,200 | 391,600 | 45,600 | 77,800 | 92,400 | 61,000 | 97,900 |
| Master's | 147,800 | 53,700 | 7,000 | 13,500 | 30,000 | 19,000 | 24,700 |
| Doctorates | 165,500 | 41,300 | 4,300 | 9,100 | 89,300 | 5,000 | 16,400 |
| <i>Percent</i> | | | | | | | |
| Bachelor's | 100% | 51% | 6% | 10% | 12% | 8% | 13% |
| Master's | 100% | 36% | 5% | 9% | 20% | 13% | 17% |
| Doctorates | 100% | 25% | 3% | 5% | 54% | 3% | 10% |

SOURCE: National Science Board, Science and Engineering Indicators, 2006, Appendix Table 3-9.

issues in applied mathematics and the workforce-oriented geosciences. Interaction with students and research productivity dominate faculty concerns in microbiology/biotechnology where the master's degree is usually a stepping-stone to the doctorate.¹³

CGS also notes, however, that "recent shifts in the professional character of master's education in general and the growth of a new type of professional master's degree within the past decade signal an intent to better prepare graduates for entry-level professional careers to respond to employer and local/regional economic development needs."¹⁴ The drivers of change deserve comment as they bear on how new professional-focused master's degree programs are evolving.

First, there are the demands of the marketplace for workers who can enter with key workplace skills, including the ability to:

- communicate in writing;
- make presentations;
- contribute as a member of an often interdisciplinary team;
- manage projects effectively;
- understand and work toward organizational goals (for example, profits, missions);
 - understand legal, regulatory, and international dimensions of science-based work;
 - understand the commercialization process and how to translate knowledge into product or process innovation; and
 - understand and apply ethical considerations.

Second, evolving science and technology enables or creates fields and lead to new opportunities within industry. As noted in Chapter 1, discoveries in physics led to advances in data storage that in turn have made such new fields as business intelligence possible. Similarly, the growth in computing power has made possible such fields as bioinformatics, computational finance, and computational linguistics. The application of science to criminal investigation has spawned a revolution in forensic science. These fields require new talent, that is, personnel with advanced science education and practical workplace skills.

Further, scientific advances that led to the growth of the biotechnology industry now present opportunities for master's-educated professionals who can contribute even more to the industry as it matures and requires individuals who have management and leadership skills. Similarly, in the

¹³Commission on Professional in Science and Technology. Science Master's Education Surveys, <http://www.sciencemasters.org/Surveys.cfm>.

¹⁴CGS, *Professional Science Master's Education*, 4, 8.

information technology industry, the need to provide computer services to clients in a systemic way has generated the need for individuals who have deep knowledge of computing but also the kinds of skills noted above. It has indeed led to a new field: service science, management, and engineering (SSME).

The situation in biotechnology and pharmaceuticals sheds more light. The number of doctorate holders in the biological sciences who work in industry—particularly the research-intensive biotechnology industry—has been growing at a faster rate than the number working in academia. If the trend continues, the field will soon look like chemistry: the majority of Ph.D.s work in industry. But the biotechnology industry is maturing and, consequently, its workforce is changing with employment growth in such positions as project manager, laboratory manager, clinical trial monitor, and regulatory affairs specialist that can be filled by graduates of professional science master's programs. Indeed, increased innovation results not only from scientific discovery, but also from the work of firms to commercialize these discoveries. The pharmaceutical industry is a striking example of this. In this post-genomic era where new discoveries in human biology are being announced at a regular rate, the drug development pipeline has not kept up with the pace. The lack of innovation is not due to a lack of scientific talent but rather to a lack of scientific talent that knows the commercialization process. This is where PSM programs and KGI's MBS program can have a true impact. They can educate individuals to not only understand the science but also understand how to commercialize it.

Today many students who might have useful and interesting careers in the sciences are not attracted to graduate school in these fields. To many (and to the undergraduate faculty who advise them), graduate education is equated with doctoral education and they have observed that, in many fields, Ph.D. programs are of indeterminate lengths and lead to either uncertain career outcomes or certain career outcomes that are not attractive. Master's education may be more appropriate, cost-effective, and attractive for these students. A professional master's program that, unlike the traditional master's or the Ph.D., is geared to the workplace provides clarity as to curriculum content, time to degree (generally two years), and what one will be able to do upon graduating.

Directors of master's programs in the sciences that are geared to the workplace argue that the students they are attracting are not typically the same ones who would have been attracted to doctoral education. A few graduates from these programs do go on to earn Ph.D.s, but most choose master's programs to advance their careers in industry, government, or nonprofit organizations. Further, their demographic profile differs from that of doctoral students. For example, 31 of 47 (66 percent) students in

the applied genetics professional science master's degree program at the University of Connecticut are women. This is representative of a national pattern of serving underrepresented groups. Of approximately 3,400 students enrolled in professional science master's degree programs in the fall of 2005, about 50 percent were women, 80 percent were U.S. citizens, and 9 percent were from underrepresented minority groups—all percentages higher than for graduate enrollment in the natural sciences overall.¹⁵

As Carol Lynch of CGS noted in her presentation to the study committee, these programs are attractive to students who want to work in nonacademic sectors, interdisciplinary careers, team-oriented environments, managerial or other professional level positions, or emerging areas of science and scientific discovery. They appeal to students who are seeking career advancement, are looking to gain a competitive edge, or are reentering the workforce in order to refine professional and technical skills.¹⁶

NEW PROFESSIONAL PROGRAMS: MBS AND PSM

While the baccalaureate was the entry-level degree for many professional positions in industry and government in the decades after World War II, many employers now recognize the value of staff who have advanced training, often at the master's level, that responds to changing competitive needs. Consequently, there is a need for flexibility in graduate education to address employer requirements and workforce needs.

Sheila Tobias, Daryl Chubin, and Kevin Aylesworth, in *Rethinking Science as a Career*, postulated that master's programs could produce graduates who provide the same level of "expertise and leadership" as professionals do in other fields. They would do so by having the ability "to use the products of scholarship in their work and by being familiar with 'the practical aspects of emerging problem areas.'"¹⁷ In an increasingly complex economy, professionals who can bring advanced, often interdisciplinary, application-oriented scientific knowledge to their position can readily contribute to the objectives, programs, and projects of employers in industry, government, and the nonprofit sector.

Philanthropy has played a recent and important role in facilitating the development of professional master's programs in the natural sciences as it had earlier in the development of professional education in the

¹⁵Linda Strasbaugh, University of Connecticut, presentation to the study committee, July 14, 2007. Carol Lynch, Council of Graduate Schools, "Professional Science Master's Degrees: Background and Overview," presentation to the study committee, March 28, 2007.

¹⁶Lynch, *ibid.*

¹⁷Sheila Tobias, Daryl Chubin, and Kevin Aylesworth, *Rethinking Science as a Career: Perceptions and Realities in the Physical Sciences* (Research Corporation), 92.

United States in such areas as business, public health, and medicine. (See Appendix F.) In 1997, the William M. Keck Foundation provided initial funding of \$50 million to launch the Keck Graduate Institute of Applied Life Sciences (KGI) as an independent college within the Claremont Colleges Consortium. KGI played a pioneering role in master's education by developing a two-year program in applied life sciences that culminates in the professional master of bioscience (MBS) degree. (See Box 2-3.) The Alfred P. Sloan Foundation has been especially instrumental in promoting broadly the development of master's programs that produce science-educated professionals. The foundation has provided seed money to establish more than 120 "Professional Science Master's" (PSM) programs in 50 institutions across 20 states. (See Box 2-4.)

PSM programs prepare graduates for work in science outside of academia, which leads to a wider variety of career options than traditional graduate programs provide.¹⁸ The MBS and PSM have been developed with several core, defining features in mind, namely, that professional master's education can provide:

- additional scientific knowledge beyond a four-year bachelor's degree;
- more interdisciplinary training, often in informatics, computation, or engineering, than a typical science degree, which allows a student to bring relevant knowledge from a variety of fields to the workplace;
 - a focus on acquiring scientific and technical knowledge that can be applied in a variety of positions in business, government, or nonprofits rather than acquiring research skills as provided in a doctoral program;
 - a perspective on a business culture that values applied research and commercialization of scientific discovery; and
 - job-relevant skills in teamwork, project management, communication, business administration, statistics, ethics, and legal/regulatory issues.

Sheila Tobias and Lindy Brigham have noted, "Some programs are more interdisciplinary than others, but all PSM tracks, without exception, feature a quantitative and/or analytic approach to their subject."¹⁹ (See Box 2-5 for the Council of Graduate Schools' Guidelines for Formal Recognition as a PSM program.)

Careful attention must be paid to the way courses and curricula are

¹⁸The detail in this section draws from Lynch, *ibid.*; Sheila Tobias and Lindy Brigham, "Report on PSM Programs: Distillation of 2005 Questionnaires," unpublished report to the Alfred P. Sloan Foundation, March 31, 2006; and CGS, *Professional Master's Education*.

¹⁹*Ibid.*

Box 2-3

Keck Graduate Institute of Applied Life Sciences

The Keck Graduate Institute of Applied Life Sciences (referred to simply as KGI) was founded in 1997 to address the needs of both biology-focused students and the life sciences industries. The William. M. Keck Foundation provided an initial funding of \$50 million (current use and endowment) to establish KGI. An additional \$20 million grant from Keck and \$30 million from other sources has been invested subsequently. KGI is a member of the Claremont Colleges Consortium, in Claremont, California.

Initially, KGI's sole degree was the two-year master of bioscience (MBS). The Fully Employed Master of Bioscience Program was added this year for full-time employees. This three-year program is delivered via distance learning and evening classes. The MBS curriculum consists of about 70 percent science/engineering and 30 percent management/ethics, with a strong emphasis on teamwork and problem solving. A summer internship is required as well as an industry-sponsored team project in the second year.

KGI's founding president, Henry Riggs, was formerly the president of Harvey Mudd College, also a Claremont Colleges Consortium member. His vision for KGI grew from the following observations and assumptions:

- The 21st century would be dominated by the life sciences, just as the 20th century had been dominated by the physical sciences.
- Engineering education is rooted in the physical sciences, giving short shrift to the biological sciences.
- Life-science-based companies are underserved by the engineering education community.
- Many positions in life-science-based companies do not require the scientific research depth that is characteristic of the Ph.D. degree.
- Ph.D. programs are inefficient for students (and employers) seeking bioscience professional and managerial careers outside the basic research function.
- A project-based, team-oriented curriculum with a strong management component and close ties to industry was needed.
- The innovative curriculum and structure required would be difficult to develop within an existing, conservative higher education institution, particularly a research university. Therefore, a new and free-standing school was needed.

KGI enrolled its first students in 2000. The 200 MBS graduates from its first six classes are now employed in a variety of positions (typically not basic research) in pharmaceutical, biotechnology, medical device, and related companies. One employer alone, Amgen, has hired about 20 percent of KGI's graduates. The KGI Board of Trustees and Advisory Council include representatives of industry, particularly in biotechnology.

Box 2-4
**Alfred P. Sloan Foundation Professional
Science Master's Initiative**

The Alfred P. Sloan Foundation pioneered the development of professional science master's programs designed to graduate students who would bring both advanced scientific knowledge and practical, professional skills to the workplace. The Sloan Foundation, from January 1997 to September 2007, had approved a total of \$17.5 million in grants to promote the PSM and to establish PSM programs, of which \$15.9 million has been paid to date. These funds include grants to institutions, university systems, the CGS, the Commission of Professionals in Science and Technology, science societies, and other organizations that promote the PSM.

As a result of Sloan's seed funding, there have been more than 120 program tracks in 50 institutions across 20 states created in the past decade. Sloan initially provided \$125,000 per institutional program track for start-ups in research universities. Later, as knowledge accumulated about how to launch a PSM track, the amount per program dropped to \$90,000 to \$100,000. This effort resulted in the establishment of about 60 program tracks at research institutions and was followed by a particular push to establish 12 single-track programs in bioinformatics. In a second-phase effort that began in 2002, Sloan provided planning grants of \$7,000 to master's-focused institutions for the development of program proposals. Implementation awards of \$40,000 per track were provided in response to successful applications, which resulted in about 30 additional program tracks at master's institutions. In a more recent phase beginning in 2005, Sloan has also provided funding for system-wide PSM efforts such as one in the California State University system that will result in 16 programs across 112 campuses.

Key aspects of the PSM initiative are listed below.

- PSM programs are concentrated in the biological sciences, mathematics, physical sciences, and computer science. The institution identified the scientific focus of a program track. Very often programs are interdisciplinary in nature.
- About 70 percent of coursework in a PSM curriculum typically focuses on science. PSM programs also include what is often referred to as a "plus" component, which focuses on such workplace skills as communication, project management, interdisciplinary teamwork, ethics, and, as appropriate, business, legal, or computation.
- Programs typically have external advisory boards. Programs see industry, government agencies, and nonprofits as potential employers. Programs are required to offer a summer internship for students.
- A new association of PSM directors, the National PSM Association, was formed in 2007. This association will also serve as a clearinghouse of information about PSM programs.

SOURCES: Carol Lynch, "Professional Science Master's Degrees: Background and Overview," presentation to the study committee, March 28, 2007. Sheila Tobias and Lindy Brigham, "Report on PSM Programs: Distillation of 2005 Questionnaires," unpublished report to the Alfred P. Sloan Foundation, March 31, 2006. Council of Graduate Schools, *Professional Master's Education: A CGS Guide to Establishing Programs* (Washington, DC: Council of Graduate Schools, 2006).

Box 2-5
Guidelines for Formal Recognition as a Professional Science Master's (PSM) Program by the Council of Graduate Schools

The Professional Science Master's (PSM) degree is a unique professional degree grounded in science and/or mathematics and designed to prepare students for a variety of career options in business, government, or nonprofit organizations. The degree combines advanced coursework in science and/or math with an appropriate array of professional skill-development activities to produce graduates highly valued by employers and fully prepared to progress toward leadership roles. The PSM is designed to be self-contained and is *not* a traditional master's degree earned *en route* to or from a Ph.D. degree.

The following criteria are intended to provide guidance to faculty and institutions planning new PSM programs, or to assist leaders of existing programs who feel their programs meet the criteria to be recognized as a PSM or who wish to modify their programs in order to be recognized as a PSM. The following characteristics are deemed important for a master's program to qualify for PSM status.

- Total credits equivalent to a standard master's degree (approximately two years, full-time equivalent, including projects and internships).
- A majority of program course work in graduate-level science and/or mathematics courses in one or more disciplines. An interdisciplinary curriculum is highly desirable.
 - Program quality assurance should be provided using the faculty-based mechanisms normally used by the institution for graduate programs in order to ensure institutional integration and sustainability. It is understood that the professional nature of the program may lead to substantial participation by nonacademic practicing professionals, for example as adjunct faculty course instructors or student internship mentors.
 - The professional skills component (often called the "plus" component of a "science-plus degree") may consist of a variety of relevant courses and activities developed in consultation with prospective employers. Examples include business basics, legal and regulatory issues, finance and marketing, communication and teamwork, and are often developed in collaboration with appropriate academic units outside the sciences or taught by adjunct faculty from the targeted employment sector. In addition to courses and workshops, professional skills are usually enhanced by internships and problem-based projects sponsored by employers. The professional component should result in a portfolio of experiences recognized by and involving the client employers.
 - An active and engaged client advisory board. Examples of board and/or individual-member functions include providing advice on the program curriculum, assisting with internships and placement, assisting with project-identification, and/or interacting individually with students.
 - A commitment to attempt to track the career trajectory of every graduate in order to help assess program outcomes and success.
 - Agreement to use the name "Professional Science Master's" and the PSM logo on Websites and advertising brochures. In turn the program will be listed on CGS national PSM websites and data bases, and will be included in CGS PSM promotional activities.

developed. A successful curriculum requires more than adding “practical professional skills” onto a science base. An effective curriculum is a balance of knowledge, skill sets, and values. Success in this endeavor requires that the culture and values of the profession be conveyed within the curriculum. In the KGI curriculum, for example, the student must be committed to the value of translating scientific discovery to a commercial product. These values run counter to some academic values. To properly instill such a value system requires a business-savvy faculty, curricular integration and a strong external industry involvement.

Moreover, for the PSM degree to be successful it must be a truly integrated educational experience. To continue with the KGI example, the MBS program started with a set of basic graduate science courses supplemented with MBA-level management courses. The success of this curriculum was not in the mix of courses but in the subsequent evolution of an integrated approach. KGI has three general types of courses: graduate science, MBA business, and “bridging” courses in such areas as pharmaceutical development, clinical trial design, and biostatistics. The integration means that topics like project management are taught in one of the science courses, the MBA business courses exclusively use case studies from the bioscience industry, and the “bridging courses” serve as the curricular glue allowing students to see science and business together in practice.

To provide another example of curriculum development, the PSM programs at the Georgia Institute of Technology have evolved into “niche science” programs: those that meet a very specific scientific industrial need by combining specific scientific skills in an interdisciplinary area. Students with a background in one scientific area are able to blend this expertise with knowledge and experience in another field. Examples at Georgia Tech include:

- 1. Human-Computer Interaction:** A program designed to prepare graduates to work with software and hardware developers and web-based companies. This program draws undergraduates who majored in psychology, computing, and computational media.

- 2. Bioinformatics:** This program prepares students for work in biotechnology companies and pharmaceutical companies. It draws students from biology, biochemistry, mathematics, and computing.

- 3. Computational Finance:** Graduates move on to work with banks, insurance companies, and other financial institutions. It draws students from mathematics, system engineering, business, and management.

- 4. Prosthetics/Orthotics:** This program prepares graduates to work in clinical prosthetics and with prosthetics/orthotics developers. Students are typically drawn from majors in applied physiology, biomedical engineering, or electrical engineering.)

These Georgia Tech programs provide interdisciplinary training that meets demonstrated industrial need and is attractive to students. They are not “science plus” programs in the sense of including separate courses to focus on professional skills, but provide skill development through the scientific training itself.

Individual PSM programs are developed with particular employers and careers in mind and with the advice of employers as partners. KGI draws advice from an advisory committee composed of industry leaders, primarily from the biosciences industry. PSM programs, meanwhile, typically have external advisory boards composed of local or regional employers. Curricula are developed based on analysis of demand for graduates, derived from information collected from potential employers. Employers also assist by mentoring PSM students, providing tuition remission for employees, providing student internships, and hiring graduates.

Thus, each program is developed according to the needs of local employers. A 2005 survey of the 89 PSM programs then existing, showed them distributed among fields as follows:

- Biosciences/biotechnology: 20 programs
- Mathematics (financial, industrial, applied, statistics): 18 programs
- Bioinformatics: 12 programs
- Chemistry or physics: 11 programs
- Geological or environmental sciences: 10 programs
- Health-related fields: 5 programs
- Computer science: 4 programs
- Forensics: 2 programs
- Other fields: 6 programs

“Some [programs] are more focused than others,” Tobias and Brigham have found, “requiring a standard science or mathematics core. Others allow for multiple areas of concentration within a single PSM, such that no two students will follow the same program.”²⁰ KGI had an enrollment of 70 students in 2005. Other programs had enrollments that ranged from 2 to 77.

Appendix G provides a side-by-side comparison of program features for the Keck MBS program, the Sloan PSM initiative, and the PSM provisions of Section 7034 of the America COMPETES Act. The commonalities between KGI and PSM have been noted above: there are several core defining features they have in common. It is important to note, however, the difference in institutional models: KGI represented the creation of a

²⁰Ibid.

new institution of higher education, while the PSM model focuses on establishing program tracks at existing institutions. Consequently, the two efforts have different financial approaches: KGI was founded with a large endowment that will continue to support the institution, while the PSM programs were individually provided funding to cover initial start-up costs that would eventually lead to self-sustaining programs.

ASSESSING EMPLOYER NEEDS

It is always difficult to project workforce demand in an accurate quantitative fashion.²¹ It is even more difficult to project such demand when the “product” is still in development and many potential customers may not even be aware of its existence. While we cannot predict the overall level of demand for PSM programs, though, we can provide some conclusions about the tenor and direction of it.

At a very general level, data appear to indicate an increase in demand for master’s-educated scientists and engineers. For example, data from the National Science Foundation (NSF), as shown in Figure 2-4, reveal that median salaries of master’s degree recipients one to five years after the degree was conferred tend to be higher than those of doctorates. More importantly, as shown in Figure 2-5, salaries of master’s degree holders in science and engineering have grown faster over the past 10 years than salaries of baccalaureate or doctorate holders.

At a more specific level, testimony to the committee revealed:

- Graduates of the mathematics-focused PSMs (financial mathematics, industrial mathematics, etc.) are attractive to banks, insurance companies, and financial and data-analysis operations of large businesses and industrial firms where they can contribute in actuarial and analyst positions. They bring higher-level mathematics, informatics, and/or analytical skills than MBAs do. PSM alumni are now working, for example, analyzing investment opportunities for companies such as Putnam or venture firms focused on the biotechnology sector.
- The number of business intelligence or analytics staff who apply mathematical modeling, data analysis, and computer simulation to solve business problems is growing in many large business and industrial companies. This work is seen as a valuable source of corporate competitiveness. Growth in business intelligence staffs, indicating that groups who perform these activities are excellent contributors, is likely to continue for

²¹Projections of scientists and engineers have gone awry on previous occasions. See National Research Council, *Forecasting Demand and Supply of Doctoral Scientists and Engineers* (Washington, DC: National Academy Press, 2000).

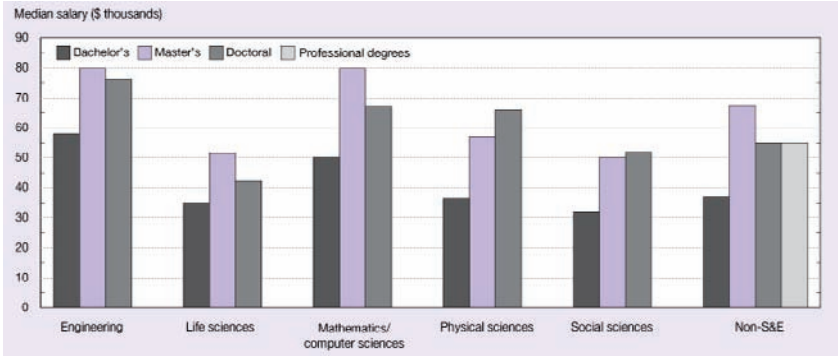


FIGURE 2-4 Median salaries of degree recipients 1 to 5 years after degree, by field and level of highest degree, 2003.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Survey of College Graduates, preliminary estimates (2003). Note: Non-S&E fields include the SESTAT categories of “non-S&E” and “S& E-related.”

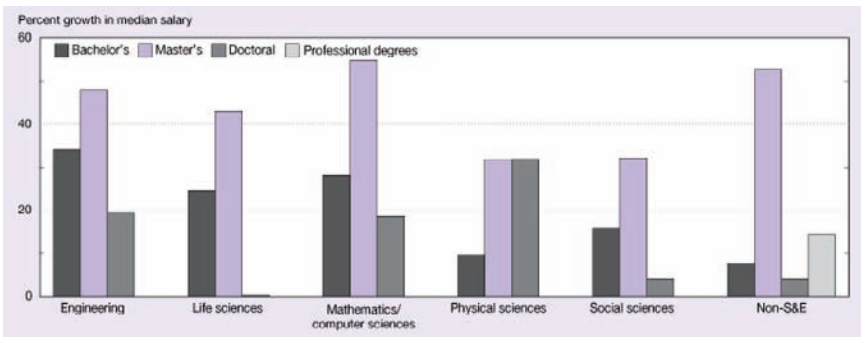


FIGURE 2-5 Inflation-adjusted change in median salary 1 to 5 years after degree, by field of highest degree, 1993-2003.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Survey of College Graduates, preliminary estimates (2003). Note: Non-S&E fields include the SESTAT categories of “non-S&E” and “S& E-related.”

some time and to percolate to more companies. Graduates of the mathematical PSMs are well qualified both for starting positions and career advancement in these workgroups. (See Box 2-6.)

- The biotechnology industry has grown and matured. While some Ph.D.s have founded and managed companies and others fill executive positions, most Ph.D.s in the biotechnology industry work in research and research management. The industry also has a growing need for people

Box 2-6 Business Intelligence

Business intelligence is the application of systems thinking, data mining, pattern recognition, mathematical modeling, statistics, computing, and simulation to solve challenging business problems. This young discipline, also called business analytics or systems analytics, began in the mid-1990s when powerful desktop computers, computer-network communications services, massive data storage options, and advanced data mining and data visualization software tools all became available.

Many large companies have created business intelligence work groups. Dow Chemical Company, Ford Motor Company, General Motors, and Proctor & Gamble are leading manufacturers with successful pioneering business intelligence efforts. This approach has proven effective in many aspects of these corporations: strategic planning, systems engineering, marketing, sales and order fulfillment, risk analysis, purchasing, warranty management, technology and capabilities analysis, supply chain management, etc. These areas greatly expand traditional mathematical efforts in computer-aided engineering. The banking and insurance industries successfully apply business intelligence to investment portfolio and credit risk analysis. Wal-Mart is a leading user among retailers of business intelligence. The health services delivery sector has begun to apply this approach to its vast and complex data.

Business intelligence projects typically involve the integration of data from internal and external sources. Data types include numeric, text, geographic, and image data. Biotechnology analytics has genomic data at its center. Data volumes are often so large that manual analysis is impossible. "Artificial intelligence" methods enable researchers to cluster data and explore for patterns. Specialists in business intelligence create mathematical models and simulations to represent problems, study business alternatives and scenarios, and generate forecasts. Successful projects provide management with insights and better decision-making tools, based on current data. These increase management awareness of business performance and dynamics and clarify competitive pressures and growth opportunities.

The new efforts in business intelligence are a significant contribution to American competitiveness in the global economy. Masters-educated graduates with appropriate preparation are ready to contribute to this growing field and are likely to become its staffing backbone. The approximately 20 mathematics-centered professional science master's degree programs available today in such fields as industrial mathematics, financial mathematics, bioinformatics, and mathematical entrepreneurship are outstanding training grounds for a career in business intelligence, as the employment opportunities afforded to their graduates testify.

who can fill positions in program management, sales, and other corporate areas.

- IBM, a corporation that transformed itself from a firm that focused on hardware to one increasingly dedicated to providing services, has initiated the creation of a new field—namely, SSME. Much like PSM

Box 2-7 **Service Science, Management, and Engineering**

The world economy is experiencing the largest labor force migration in history. Driven by an environment that includes global communications, business growth, and technology innovation, services now account for more than 50 percent of the labor force in Brazil, Russia, Japan, and Germany, as well as 75 percent of the labor force in the United States and the United Kingdom.

This unparalleled segment growth is changing the way companies organize themselves, creating a ripple effect in industries and universities that are closely tied to these organizations. For instance, historically, most scientific research has been geared to supporting and assisting manufacturing, which was once a dominant force in the world economy. Now that economies are shifting, industrial and academic research facilities need to apply more scientific rigor to the practices of services, such as finding better ways to use mathematical optimization to increase productivity and efficiency on demand.

This shift to focusing on services has created a skills gap, especially in the area of high-value services, which requires people who are knowledgeable about business and information technology as well as the human factors that go into a successful services operation. Many leading universities have begun exploring and investing in this area, working in tandem with thought leaders in the business world.

In May 2004, this group suggested that an entirely new academic discipline may be called for—first roughly described as “services science” at a summit held at IBM. Subsequent meetings have caused the discipline to evolve into the more appropriate service science, management, and engineering (SSME) title now used.

Service design, development, marketing, and delivery all require methodologies and techniques to make service businesses more efficient and scalable. Both depth and breadth are needed in technology, business, and organizational studies, even at the undergraduate level. SSME hopes to provide that depth and breadth by bringing together ongoing work in computer science, operations research, industrial engineering, business strategy, management sciences, social and cognitive sciences, and legal sciences to develop the skills required in a services-led economy.

The goal of the SSME discipline is to make productivity, quality, sustainability, and learning and innovation rates more predictable across the service sector.

SOURCE: Adapted from “Service Science, Management and Engineering,” IBM Incorporated <http://www.research.ibm.com/ssme/> and <http://www-304.ibm.com/jct09002c/university/scholars/skills/ssme/index.html> (accessed October 20, 2007).

programs, programs in this field emphasize the education of “T-shaped” employees who have depth in science and also breadth in terms of business and customer skills. (See Box 2-7.)

- The U.S. Department of Defense has documented its need to hire an increasing number of science- and technology-savvy U.S. citizens with

management skills for positions in technology, acquisitions, and logistics.²² We believe that U.S. intelligence and homeland security agencies have a similar increasing demand for employees with these characteristics. These agencies are poised to become potentially large consumers of graduates from PSM programs.

- Other federal or state agencies could also become substantial consumers. The Patent and Trademark Office of the Department of Commerce is already hiring PSM graduates into examiner positions. Others, such as the Department of Energy or the Food and Drug Administration, could hire into similar positions as well.

In general, experience with many existing PSM programs, the KGI MBS program, and IBM's SSME programs shows that graduates are well prepared to contribute in technically challenging positions in business and government. In the for-profit sector, PSM graduates may contribute in specific ways, such as program management, in large companies. For relatively smaller companies, they may be particularly valuable since there is often a need for one individual to assume several different responsibilities. This kind of flexibility and entrepreneurial spirit is characteristic of the students attracted to the PSM type degree.

Through the fall of 2005, there were 1,300 graduates of PSM programs from six cohorts. While a small number—in light of the more than 18,000 master's degrees awarded in the natural sciences (biological sciences, physical sciences, and mathematics) in the 2003-2004 academic year—the number has been growing each year. The biological sciences and applied mathematics fields are leading the way. Indeed, KGI is increasing its enrollments.²³ The Institute's graduates typically receive multiple offers. As shown in Table 2-6, about half have accepted offers by the time of graduation and nearly all who seek employment have lined up a position within six months of receiving their degrees. There are fewer PSM programs in the geological sciences and computer sciences, but most master's programs in these fields are already focused on preparing graduates for the workplace. There has been less growth in PSM programs in chemistry and physics, though that may change if government agencies

²²Dr. Ronald M. Sega, Director of Defense Research and Engineering, Testimony to U.S. Senate Armed Services Committee, Subcommittee on Emerging Threats and Capabilities, March 9, 2005. Dr. William Berry, Acting Deputy Under Secretary of Defense, Presentation on "Professional Science Masters Program: DOD Needs," to PSM Biennial Conference, Washington, D.C., October 6, 2005. Dr. William S. Rees, Jr., Deputy Under Secretary of Defense, Presentation on "DOD STEM Education: Science, Mathematics and Research for Transformation (SMART), A Defense Scholarship/Fellowship Program," to National Science Board, September 28, 2006.

²³Beryl Lieff Benderly, "Mastering the Job Market," *Science*, March 7, 2008.

TABLE 2-6 Employment and Salaries for MBS Graduates, Keck Graduate Institute of Applied Life Sciences, 2001-2002 to 2006-2007

| Employment | FY 01-02 2002 | FY 02-03 2003 | FY 03-04 2004 | FY 04-05 2005 | FY 05-06 2006 | FY 06-07 2007 |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Accepted offers as of graduation | 54% | 28% | 29% | 41% | 39% | 51% |
| Accepted offers 6 months out | n/a | n/a | 20% | 4.50% | 84% | 11.00% |
| Chose travel/further education ^a | n/a | n/a | 20% | 4.50% | 9.70% | 11.00% |
| No. of converted internships | n/a | 1 | 5 | 4 | 5 | 8 |
| Starting salary range ^a | n/a | \$34-95K | \$37-80K | \$57-96K | \$36-90K | \$55-75K |
| Salary average | n/a | \$55K | \$59K | \$72.1K | \$67.2K | \$60.6K |
| Total no. of students | 28 | 28 | 34 | 22 | 31 | 36 |

^a**Notes for Class of 2007:** As of July 23, 83 percent were employed, 17 percent were actively involved in job searches, and 16 percent were not seeking employment. Of the 6 not seeking employment, 2 students are entering Ph.D. programs and 4 are traveling. Mean salary for the 25 employed graduates is \$61,200.

SOURCE: Keck Graduate Institute of Applied Life Sciences.

in the military, homeland security, and intelligence that require technical staff see PSM graduates as a resource.

Data presented to the committee suggest that demand for these graduates is strong. In 2003, starting salaries for new hires with any master's degree in the biological sciences was \$40,000, the physical sciences \$49,000, and mathematics and statistics \$54,000. PSM graduates in these fields, on the other hand, had starting salaries of \$45,000 to \$55,000 in nonprofits and government, and \$55,000 to \$62,000 in private industry.²⁴ As shown in Table 2-6, MBS graduates from KGI have had relatively higher starting salaries, with a range of \$55,000 to \$75,000 for the class of 2007.

In addition to data showing both increased demand for master's-educated scientists and more specific demand building for a professional science master's, there has been a growing appreciation among national organizations for PSM programs. In just the last few years, the President's Council of Advisors on Science and Technology, the National Science Board, the National Governors Association, the Council on Competitiveness, the U.S. Chamber of Commerce, a group of 15 prominent business organizations, the Association of American Universities, and the Council of Graduate Schools have all recommended a national effort to develop and expand the number of PSM degree programs in the nation.

These reports represent the collective voice of government, industry, and higher education, and in each case the recommendation to establish and increase the number of PSM programs was seen as a key part of a package designed to address U.S. competitiveness and innovation. To cap it all, this past summer Congress authorized the NSF to develop a program of grants to four-year institutions to create or expand PSM programs. This was enacted in Section 7034 of the America COMPETES Act, which was signed into law by the president. (See Appendix I.)

DEVELOPING PSM PROGRAMS

The opportunity for master's-educated professionals in the sciences to contribute to our national economy is clear. But how flexible are U.S. universities willing to be in responding to changing workforce needs? The CGS has produced a guide²⁵ for establishing professional master's programs that provides advice on:

- **Feasibility planning:** Garnering faculty support, securing the support of university administrators, addressing cultural challenges, deter-

²⁴Lynch, *ibid.*

²⁵CGS, *Professional Master's Education*.

mining local/regional workforce needs, and establishing an external advisory board

- **Developing a program:** Curriculum, business/financial plan, and program approvals
- **Start-up and operations:** Appointing a program director/coordinator, staffing, advertising, recruiting, handling applications/admissions, advising, and providing student services
- **Assessing the program:** Performance, student satisfaction and outcomes, and employer satisfaction
- **Sustainability:** Program flexibility, financial viability, and institutional support.

The CGS guide, along with the results of successful PSM models across fields, provides enough practical guidance for any institution to launch a professional master's program. Initially, as Tobias and Brigham have reported, it took programs "a *minimum* of two years to plan a PSM, gain appropriate administrative approval, recruit, and actually enroll students." Now, however, they note that this "time has been reduced, partly because there are PSM models to learn from, and an outreach network from which to draw strength and advice."²⁶

The track record for PSM programs begun with Sloan seed money has been very good so far. One way to assess their progress is to discuss "those few instances where PSM programs have been discontinued." Tobias and Brigham write: "Some number of PSM tracks never made it to launch though their sister tracks on the same campus did. In almost every such instance, the faculty member who was most enthusiastic left or was promoted to a position where he/she could not manage the program."²⁷ They found that the factors compelling discontinuation of program tracks—fewer than ten nationwide—were typically external to the program as most had reasonable success at recruiting and placing students: (i) the university decided to downplay or discontinue *all* its master's programs, (ii) a PSM program was hijacked by another department wishing to capture (or recapture) master's students in the field, or (iii) senior administrators change and the new cohort decides to reverse or simply to underfund programs started by the previous administration.²⁸

"Remarkably," Tobias and Brigham conclude, "almost no programs were canceled after outside (Sloan) funding ran out." This sustainability is a key point: these programs fill an important need and become self-sustaining in the long run. For many of these programs, the long run was

²⁶Tobias and Brigham, *ibid.*

²⁷*Ibid.*

²⁸*Ibid.*

at least five years: the initial grant period was for three years, but with no-cost grant extensions almost all programs at research universities spent their initial funding over a period of five years.²⁹

Four areas require additional attention before any PSM program can be called institutionalized: faculty involvement, communication with employers, student financial support, and program delivery.

First, there remains the need to provide incentives to faculty to develop and market master's-level programs. Many faculty members in the natural sciences continue to view master's degrees as incidental and unimportant elements of graduate programs focused primarily on preparing doctoral students. Others more enthusiastically embrace professional master's programs. Somewhere in between these two extremes are the views of most faculty who are busy—focused on research, distracted by many university demands, or indifferent to master's education. They may not have the time or capacity to mentor master's students. Incentives are needed to attract these faculty to develop master's programs. Financial incentives are one possibility. Another incentive is the opportunity to interact with industry, learn their needs, and find new and interesting avenues of research and consulting. There is also an important role for scientific societies to play in promoting professional science master's programs, sharing information about programs, and encouraging and rewarding faculty in these endeavors. (See Box 2-8.)

Beyond the issue of incentives is the importance of matching faculty to courses. Core courses may be taught by existing faculty. Some of the most innovative and effective and often interdisciplinary curricular elements probably are not within the expertise of the faculty or of a faculty member teaching alone. The KGI solution to this problem has been to hire faculty with both industrial and academic experience. This option will not be open to most institutions and will present a real challenge. These institutions may bring in outside experts to teach the "plus courses" or the "plus components" of core courses in the curriculum. They may also engage in providing additional training to faculty across PSM programs at an institution.

One important component of building sustainable PSM programs and an appropriate and dedicated faculty is the appointment of a coordinator or director of the program. Unlike undergraduate programs that are mostly run (in terms of recruiting and marketing) by admissions offices, and Ph.D. programs that are mostly advisor-driven, PSM programs need a dedicated individual. Successful institutions have arranged this in different ways—sometimes as a staff person and sometimes as a faculty/staff position—but this position is typically critical to success.

²⁹Ibid.

Box 2-8 Scientific Societies and the Master's Degree

There are several varieties of scientific societies: multidisciplinary (American Association for the Advancement of Science; Sigma Xi—The Scientific Research Society), disciplinary (Federation of American Societies for Experimental Biology), and targeted to a particular underrepresented group (Association for Women in Science; American Indian Science and Engineering Society). Whatever the type, these societies are voluntary organizations that reinforce professional identity, provide forums for face-to-face interaction, and represent a special kind of “club” for those who elect to join.

Many scientific disciplinary communities and their principal professional associations are wrestling now with their role in advancing education. Given the dominance of doctoral education in the sciences it is not surprising that these associations tend to reward behavior that validates contributions and status associated with that degree—primarily advancing knowledge through research and publication. For some, however, there is now at least some philosophical discussion of the place of education broadly construed in their mission. And for others, societies have moved further ahead, making this an important transition period, both generally and potentially for master's education.

Professional societies play a vital role in the lives of scientists. They bridge the world of education to the world of work by providing members—both individuals and organizations—with access and support. These societies serve as advocates, watchdogs, certification agents, clearinghouses, and recruitment and placement services. They monitor the match between skills and opportunities, supply and demand, the marketable and the actual market.

If scientific societies are integral to learning “what matters” to excel professionally, then their role in master's education will only grow through the 21st century. To accomplish this they may develop an overall strategy for addressing education, including master's education and the PSM, in their fields. To specifically further the PSM, they could create society-wide committees on master's education, dedicate conference sessions and presentations to master's education and PSM programs, recognize faculty who have led successful PSM programs, and serve as a field-specific clearinghouse of information on PSMs.

More broadly, the Commission on Professionals in Science and Technology (CPST) manages a clearinghouse on the latest data and information about master's education in science, mathematics, and engineering. It includes a database (<http://sciencemasters.org/>) of more than 2,000 programs from over 300 institutions as well as articles, tables, and data pertaining to science master's education and the master's workforce.

Second, programs and institutions need to work continuously to develop and enhance communication with employers. At present, some external advisory boards “are very active and involved,” report Tobias and Brigham. Others, however, meet only once a year or are “nominal,” which means “advisers signed on but aren't doing any work.” Commu-

nication between higher education and industry works best, and the program developed will best suit industry's needs when there is a working and interactive relationship between a master's program and industry.³⁰

Industry advisors and representatives can help develop and interact with master's programs in many ways:

- They can participate in industry advisory councils that help oversee a program and provide a network for both input from and outreach to potential employers.
- They can provide advice on curriculum development.
- They can provide mentors, adjunct faculty, internships, financial support to programs and students, and employment for graduates.
- They can fund students' projects—KGI's MBS curriculum includes a business-sponsored team project for which businesses provide the project definition and \$50,000 per project in support.

But even with all of this interaction, programs must market themselves aggressively. Each program should have a Web site that provides such information as program goals, career opportunities for graduates, the curriculum, and members of the industry advisor council. Representatives of the program should also regularly speak about it at various local and regional gatherings of industry representatives.

Beyond this, however, there is an even broader need for marketing. The master's degree is evolving into an important professional degree in a growing array of STEM-based professions in a high-tech globally competitive world. That fact is not well understood by employers who aim to hire people just as they always have, but the benefits of employer involvement in PSM programs are substantial. Employers who serve on advisory boards, for example, have access to a pool of well-trained, highly qualified master's-level professionals for future hires. Moreover, they often get to have an "extended interview" with them prior to making an offer through internships and employer-sponsored projects and they have the opportunity to help shape their education and training through curriculum development.

A study by the California Council on Science and Technology for the California State University system provided four recommendations, each of which targeted the need to improve communication between industry and institutes of higher education.³¹

³⁰Ibid.

³¹California Council on Science and Technology, *Industry Perspective of the Professional Science Master's Degree in California: Prepared for the California State University System*, January 2005, <http://www.ccst.us/publications/2005/2005PSM.php> (accessed October 31, 2007).

1. The PSM program must establish credibility in order to be accepted on a widespread basis: "Despite recent publicity in a variety of articles... many [in industry] had never heard of the PSM, and those who had did not have a clear perception of what the degree entailed."

2. In order to succeed, the PSM must be targeted to industries where it is best suited: employers most likely to support the PSM were large companies with multidisciplinary interests, companies with an interdisciplinary focus, and government agencies. Additional "missionary work" is needed to establish the credibility of professional master's degrees in the biotechnology industry.

3. Industry and universities need to develop better working relationships: many connections are on a personal basis. Beyond collaboration through advisory boards, programs/institutions should invite people from industry to regularly serve as guest speakers, and program heads should attend and speak at industry association meetings.

4. Statewide partnerships should be explored. The development of statewide networks or a high-level advisory board for the chancellor's office of the California State University system was seen as a way to facilitate placement of interns and graduates and to continue to publicize the PSM degree.

By addressing these recommendations, information and perception gaps can be bridged, further contributing to program expansion.

Third, there is a need to address the question of what is—and how to provide—adequate student financial support. Originally, the Sloan Foundation anticipated that, being *professional*, PSM students would fund their master's educations with the expectation that their future earning would make their investments in themselves and their careers worthwhile in the long run. Tobias and Brigham report that "student support is probably the factor limiting expansion [of programs], especially as PhD programs in mathematics and the physical sciences become more aggressive in their recruitment efforts."³² KGI, by contrast, assumed some student support was critical. Initially KGI provided students with 100 percent support during their first year of study. They planned for first-year support for students to decline to an average of 50 percent over the next several years which KGI successfully accomplished, but some student support remains.

As noted earlier, students attracted to PSM programs typically differ from other graduate students. They include more women and, in general, tend to be older. For the most part, they are students who would not have gone back to graduate school in a program other than a PSM, which

³²Tobias and Brigham, *ibid.*

provides opportunities for a change in career or advancement within a current career. Additional student financial support will provide incentives to individuals—particularly underrepresented minorities and those from disadvantaged backgrounds—to pursue PSM degrees. As a result, programs will be able to expand enrollment and produce more science-trained professionals who will contribute to our economy.

Fourth, additional thought should be given to the delivery of PSM programs and courses. KGI has just now established a program for students who are working full time. The program takes three years instead of two because the students participate in the program on a part-time basis. Moreover, to address the needs of students who are already busy professionals, KGI is formulating plans to deliver the courses online or, if campus based, in the evenings or weekends. PSM programs could potentially make greater use of online course delivery. Institutions like the University of Maryland University College have pioneered the development of a successful model of distance education that is now technology driven and delivers course content to students globally.³³ This model could possibly be adapted for certain courses or programs for PSM degrees as well.

³³Susan Aldridge, President, University of Maryland University College, presentation to the study committee, July 16, 2007.

Mastering the Future

In the course of our nation's history, our leadership has made bold moves to equip our people with the skills and knowledge needed for the future. These moves, reflecting the needs of their times, have been critical to the social and economic development of our nation. The Morrill Land Grant Act of 1862 provided states with the resources to establish and grow postsecondary educational institutions whose mission would include the development of agriculture and engineering and increasing access to higher education. A second Morrill Act, passed in 1890, required states to show that either race was not a factor in admission to state universities or they had established institutions of higher education that would serve the states' African-American population. This resulted in new institutions that are now among the nation's historically black colleges and universities.

Similarly, the Serviceman's Readjustment Act of 1944—commonly known as the GI Bill—provided a range of benefits for World War II (and later Korean War) veterans after they returned from war, including payment of tuition for vocational or college education. This benefit dramatically altered educational opportunities for Americans, with substantial social benefits for those who used this as a stepping-stone to the middle class and with huge gains to the American economy, which benefited from a growing number of educated workers.

In addition to these landmark developments, the federal role continued to grow in key ways. Enacted by the U.S. Congress in 1958 in response to the launch of Sputnik and the emerging threat posed by the

Soviet Union, the National Defense Education Act (NDEA) provided support for education in critical areas of national need. NDEA provided funding to enhance research facilities; fellowships for thousands of graduate students pursuing degrees in science, mathematics, engineering, and foreign languages; and low-interest loans to undergraduates in these fields. Funding for NDEA (adjusted to 2008 U.S. dollars) was about \$500 million to \$600 million. By the 1970s, other federal programs had largely superseded NDEA, but those provided an important further expansion of federal support for undergraduate education through student loans, tax policy, and grants.¹

There is growing consensus that we are again at one of those moments when we need bold action. Technology has driven American growth and provides opportunities for the future. The competition for talent, both domestically and globally, is challenging U.S. technological leadership, and the nation needs to act. Talent is one of the important keys to innovation and competitive success. The master's-trained segment of the science workforce is pivotal: strengthened master's education in the natural sciences will prepare professionals who bring scientific knowledge and also the ability to anticipate, adapt, learn, and lead where and when needed.

The traditional science master's degree does not meet this need. A reinvigorated master's degree in the natural sciences provides an opportunity to meet this challenge by training adaptive innovators and service scientists solidly based in science, linked to industry, and possessing communication, business, and teamwork skills. The enhanced master's programs recommended in the following section will provide students with connections to real-world problems. The graduates will be entrepreneurial, experienced in teamwork, and focused on problem solving. The programs will produce graduates who have a deep knowledge of science, the ability to work at the intersection of science fields, and practical business skills that will allow them to make a contribution in the workplace from day one.

The time is now right to accelerate and spread nationally the development of this new concept—that is, professional science master's (PSM) education that is interdisciplinary in character, strongly emphasizes effective communication and problem solving, and provides an understanding of entrepreneurial skills and technical innovation. Successful programs that have responded to this challenge have engaged collaboratively a broad set of stakeholders—employers, prospective students, faculty, government agencies, and other funders—in designing curricula, defining

¹See Box 7-2. The National Defense Education Act. National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, *Rising Above the Gathering Storm*, 169.

education projects and internships, and advocating this new educational opportunity.

These programs do not displace traditional master's programs. Rather, faculty develop them to serve the needs of students who require a different graduate experience for the workplace: banks, insurance and financial companies, and large firms who hire graduates of PSM programs in financial and industrial mathematics; a maturing biotechnology industry with a growing need for middle managers who have both scientific knowledge and broader business skills; services corporations like IBM that require employees with depth in science and breadth in business and customer skills; and government employers (particularly in the military, intelligence, and homeland security agencies) that have an increasing need for science- and technology-savvy staff, particularly those with an interdisciplinary background.

FINDINGS

After extensive information gathering and deliberation, we recommend concerted action to accelerate the development nationally of professional science master's education. This recommendation is based on the following findings:

1. In the natural sciences, the master's degree is as varied in its purpose as it is in any broad field. Master's degrees in fields such as physics, chemistry, the biological sciences, and mathematics have typically signified either a "stepping-stone" en route to the doctorate or a "consolation prize" for those who were not admitted to candidacy or dropped out. Master's degrees in computer science and the geosciences, by contrast, have typically prepared graduates for the workplace. In the early part of the 20th century, professional and graduate education took divergent paths and physics, chemistry, and biology are exemplars of classical graduate education. Professional degrees, by contrast, served as credentials for practice. During the last 50 years, tremendous growth in master's degrees awarded in fields such as education and business administration, however, has indicated the professionalization of master's education. This trend has recently touched natural sciences such as the biological sciences and mathematics where traditional master's programs continue—as they should—alongside the recent development of professional science master's programs.

2. Higher education institutions are responding to the increased need for professionals who bring both scientific knowledge and professional skills to the workplace by developing PSM programs in the natural sciences that provide:

- Advanced education in the sciences;
- Opportunities for more interdisciplinary training, often in informatics, computation, or engineering, than a typical science degree;
- Hands-on experiential learning through internships and team projects;
 - Professional skills and experience in communication, teamwork, project management, business administration, innovation and commercialization, legal and regulatory issues, ethics, and/or the international environment; and
 - Strong links with employers in industry, government, and nonprofits through external advisory boards, curriculum development, internships/co-ops, mentoring, sponsored team projects, and employment.

Examples of PSM programs that were presented to the committee showed that professional master's education in the sciences can provide tailored, cost-effective, and attractive education and training to meet student and employer needs.

3. Professional master's programs can and do attract students who want to work in nonacademic sectors, interdisciplinary careers, team-oriented environments, managerial or other professional-level positions, or emerging areas of science and scientific discovery. They appeal to students who typically do not pursue doctoral education, but seek career advancement, look to gain a competitive edge, or want to refine professional and technical skills in order to reenter the workforce.

4. Salary and placement data for PSM and MBS graduates indicates strong and growing current demand for master's-level science professionals. Testimony to the committee provided specific examples of the demand for these graduates from biotechnology companies, banks and financial corporations, information technology firms, and government agencies. There is, moreover, broad support for expanding PSM education, voiced by the President's Council of Advisors on Science and Technology, the National Science Board, the National Governors Association, the Council on Competitiveness, the U.S. Chamber of Commerce, the Association of American Universities, and the Council of Graduate Schools. We cannot, of course, precisely project future demand as many factors influence labor markets at any particular point in time. Our experience as employers and educators, however, leads us to believe that the current strong demand will continue to grow in the long run and that the nation will benefit from the development of a cadre of science-educated professionals. The graduates of PSM and MBS programs will become process managers, service scientists, investment analysts, patent examiners, science and technology acquisition managers, forensic scientists, or other types of professional scientists. From among these, in the judgment of this committee, some

number will also emerge as leaders, executives, and in industry, government, and non-profit organizations.

5. Our review of the evolution of professional programs in other fields revealed the important role of foundations in shaping both the content and growth of programs in medicine, business, public health, and other areas. Foundation support—from the William M. Keck Foundation and the Alfred P. Sloan Foundation—has been critical as well in the development of professional master’s programs in the sciences. In the committee’s judgment, future funding and support for professional master’s programs should be a responsibility shared by the federal government, state governments, philanthropic organizations, employers, and higher education institutions.

RECOMMENDATIONS

In August 2007, Congress passed the America COMPETES Act, which authorizes the National Science Foundation (NSF) to develop and implement a program of grants to higher education institutions that may use them to develop or expand PSM degree programs. We see this as a step along the road toward growing a large cadre of science-trained professionals in the United States who will address our nation’s workforce needs, and by extension our competitiveness, health, and security. Yet stakeholders—notably the federal government, state governments, philanthropic institutions, national associations, higher education institutions, employers, and students—must undertake additional steps in order to secure the long-run success of our nation’s efforts to address this important workforce need.

Federal Government

1. To achieve specific national goals as well as meet general demand for science-trained professionals, we recommend the federal government expand the PSM program authorized in the COMPETES Act so that it is the responsibility of the NSF and all other major federal science agencies² as well. We recommend that each agency program include two components: (1) a program of institutional PSM grants competitively awarded to four-year higher education institu-

²The major federal science agencies are those that have the largest shares of federal research and development spending and together comprise more than 90 percent of such spending. These include, in addition to the NSF, the Departments of Defense, Energy, Health and Human Services (National Institutes of Health), Commerce (National Institute of Standards and Technology and National Oceanic and Atmospheric Administration), Agriculture, Interior, and Homeland Security, and the National Aeronautics and Space Administration.

tions for the establishment and start-up operations of PSM programs and (2) a program of National Innovation Scholarships that provides need-based scholarships for U.S. citizens who will use them to pay for tuition and expenses when they enroll in PSM programs. It is critical that Congress appropriate funds for this multi-agency program beginning in fiscal year 2009 and at an appropriate level. If this program flourishes and demand for PSM graduates increases as much as the committee expects it will, then program funding will need to be considerably larger than the levels that Congress has so far authorized.

The federal government should create and fund a new program whose goal is to develop and expand professional master's education in the natural sciences that meets local, regional, or national needs. We expect that, to meet those needs, many of these new master's programs will be interdisciplinary in nature and that they, like the Sloan- and Keck-supported programs, will provide opportunities for students to acquire skills in communication, teamwork, project management, or other areas of business, ethics, or law. The America COMPETES Act authorizes the NSF director to develop a program that will award grants to four-year institutions to create or improve PSM degree programs in high-need fields. We support the creation of this NSF program and recommend that Congress also authorize other agencies across the federal government to develop such programs to address particular needs associated with the fields of science important to their missions.

Given the national need for, and the return to the nation of, educating science-trained professionals at the master's level, we recommend that the federal government provide substantial funding for this national program. The America COMPETES Act authorizes the NSF to provide up to 200 institutional grants to create or expand PSM programs in four-year institutions in high-need fields that have an emphasis on practical training and preparation for the workforce. To fund these institutional programs the act authorizes funding for NSF to implement Section 7034 for up to \$10 million in FY 2008, \$12 million in FY 2009, and \$15 million in FY 2010. As noted above, these annual authorization levels for federal funding will be inadequate if this program flourishes and demand for PSM graduates increases as we believe it will. It is our hope, moreover, that overall funding and support for institutional PSM programs will be a shared responsibility of the federal government, state governments, private philanthropy, employers, and universities.

To meet the goals of this effort, it is critical that federal funds support institutional programs that will produce graduates who meet employer needs—local, regional, or national. We expect that in their applications for

federal program support, institutions will demonstrate that they have a substantial and productive partnership both with employers and with the professional practice community. These partnerships should involve participation of employers and practitioners on an external advisory board and financial and/or in-kind support for the program. In-kind support may include mentoring, internship opportunities, support for hands-on team projects, and other program interaction. To help promote productive institution-employer relationships, we also recommend research on best practice in fostering interaction between employers and higher education programs in order to facilitate communication about employer needs and the development of curricula about those needs. Funding for this research could be provided by the federal government or private foundations. Either way, it would benefit PSM programs and also communication about other degree programs.

We recommend that institutional grants provide funding for at least five years and perhaps up to ten. Experience with PSM degree programs has shown that five years is the minimum amount of time needed to obtain a return on the initial investment establishing a program. Institutional programs funded by the Sloan foundation were, initially, provided grants for a three-year period. Almost all of the institutions receiving those grants requested no-cost extensions that typically extended the grant period to about five years. To become permanently established, sustainable, and able to reach full capacity, programs will likely need support for up to ten years, with funding past year five linked to demonstrable progress.

The America COMPETES Act establishes that the NSF director will carry out program evaluations and report the results of such evaluations to Congress. More specifically, the act mandates that the NSF director shall “complete an annual evaluation of each program assisted by grants under this section, requiring that any program that fails to satisfy the performance benchmarks developed under subparagraph (A) shall not be eligible for further funding.” While we agree with the provisions to report outcomes, and that NSF should coordinate this function across agencies, we believe that meaningful reporting will only be available after the program has been in place for five years.

The America COMPETES Act mandates that the NSF director shall establish a clearinghouse—in collaboration with four-year institutions of higher education (including applicable graduate schools and academic departments) and industries and federal agencies that employ science-trained personnel—to share program elements used in successful PSM degree programs and other advanced degree programs related to science, technology, engineering, and mathematics (STEM). Further, according to the act, the NSF director shall make the clearinghouse available to institu-

tions of higher education that are developing PSM degree programs. With support from the Sloan Foundation, *Sciencemasters.com* has provided a clearinghouse of information on PSM programs. This site was originally maintained by Sheila Tobias from 1997 to 2006 and has since been maintained by the Council of Graduate Schools. A new association of PSM directors, the National PSM Association (NPSMA), was formed in 2007. This association, which also has Sloan Foundation support, will also serve as a clearinghouse of information about PSM programs.

Lastly, financial support for students is critical to the overall success of our nation in developing a cadre of science-trained professionals in the United States. The participation of students from all backgrounds, including those from economically disadvantaged families, is essential to this effort. While some students will be able to pay tuition and living expenses to obtain a master's education through their own funds or by taking on a minimal amount of debt, others from more disadvantaged backgrounds generally cannot afford to pay for two years of such costs. Significant debt from undergraduate programs prevents them from financing master's-level education through new loans. As an integral component of the PSM program, we recommend, therefore, the creation of a substantial federal program—the National Innovation Scholarship (NIS) program—to provide needs-based financial assistance to U.S. citizens who will use them to pay for tuition and expenses when they enroll in PSM programs. The typical federal grant to support tuition and expenses for graduate students is currently \$40,000 and we recommend similar support for PSM students. Enrollment in PSM programs should, of course, be open to students from everywhere in the world and we welcome all PSM graduates to remain in this country and contribute to our economy and society. Furthermore, institutions should provide financial subsidies from their own funds to either U.S. or non-U.S. citizens as appropriate. We recommend that the taxpayer-supported NIS program be focused on U.S. citizens as this represents an ideal opportunity to both help domestic students who might not otherwise have the financial wherewithal to attend to graduate school and simultaneously bolster our science workforce by attracting more domestic students to graduate study in the sciences.

State Governments

2. State governments, which have a long history of efforts in economic development, should regard PSM degree programs as critical to producing a cadre of science professionals who can play an important role in managing and growing science- and technology-based industries in their states. Along with the federal government, states should provide funding for the creation and

expansion of these programs to target particular state and regional needs.

State governments have a long history of working to spur economic development. Recently, many states have focused on the role of science, technology, and innovation in growing businesses and industries and the way higher education and workforce development can contribute to broadening the economic base. Some states, moreover, have begun to focus even more specifically on the health and growth of their STEM workforce.

We recommend that state governments invest in and regard PSM degree programs as critical to producing a cadre of science professionals who can play an important role in managing and growing science- and technology-based industries in their states. California, for example, now has master's programs in the biosciences and biotechnology that serve its growing biotechnology sector. The California State University system is rolling out a system-wide plan that will provide new PSM programs in 16 fields on 12 campuses. A similar system-wide effort is under way in North Carolina and other states are now planning the same. Coordination of efforts among state governments, state university systems, and employers will help maximize the potential of these efforts to contribute to long-term state economic growth.

Philanthropic Organizations

3. Philanthropic institutions should continue to play a role in creating and sustaining PSM degree programs and otherwise spurring innovation in master's education. Foundations can provide matching funds for federal grants, funding to assist students with financial aid, and the seed money for the establishment of a base of new programs in a specific field or in support of a specific industry.

The role of the William M. Keck Foundation in establishing the Keck Graduate Institute and the Alfred P. Sloan Foundation in providing seed money for more than 120 PSM program tracks at 50 institutions has been critical to establishing the need for and usefulness of master's-level professional programs in the sciences to meet the needs of science-based employers. The efforts by and impacts of these private foundations mirror those of others that have pioneered new programs in fields outside of the natural sciences. Two noteworthy examples are the Whittaker Foundation, which focused on developing biomedical engineering as a discipline, and the Franklin W. Olin Foundation, which has played a role in pioneering a new approach to engineering education.

We encourage philanthropic institutions to continue to play a role in creating and sustaining PSM degree programs, and even endowing new institutions as warranted. Foundations can provide matching funds for federal grants, funding to assist students with financial aid, and the seed money for the establishment of a base of new programs in a specific field or in support of a specific industry.

Professional Societies and Industry Associations

4. Each professional society in the natural sciences and industry association in high-technology or science-based industries should develop an overall strategy for addressing higher education in its field that includes the PSM and specific actions to help create and sustain PSM programs and other innovations.

In advancing U.S. competitiveness, professional societies are in a position to contribute by bridging professional practice and academia. Professional societies should support the creation of PSM programs in their fields or in interdisciplinary fields to which their discipline contributes. We recommend that each professional society in the natural sciences develop an overall strategy for addressing higher education in its field. This strategy should include the PSM and specific actions to help create and sustain such PSM programs as:

- Creating a society-wide committee on master's education in the field, parallel to those that focus on doctoral and postdoctoral education
- Highlighting or facilitating PSM programs through conference sessions and presentations
- Providing a field-specific clearinghouse of information on PSM programs and job opportunities for PSM graduates
- Recognizing the professional contributions of faculty who lead or participate in successful PSM programs

Industry associations may similarly play a critical role in identifying workforce needs and providing a catalyst for the development and nurturing of PSM programs. We recommend that associations in high-technology or science-based industries develop an overall strategy for higher education. This strategy should include the PSM and specific actions to help create and sustain such PSM programs as:

- Creating an association committee on higher education in the field that includes PSM education

- Highlighting or facilitating PSM programs through conference sessions and presentations
- Providing an industry-specific clearinghouse of information on PSM programs and job opportunities for PSM graduates
- Providing outreach to employers that could work with local higher education institutions to develop and sustain PSM programs

In addition, we encourage the further development of the NPSMA and the engagement of other associations with it. This new organization supports PSM programs, engages businesses, industries, nonprofit organizations, and government agencies, and promotes the PSM as a graduate degree of choice for students in science, mathematics, and technology. The NPSMA has a unique opportunity to strengthen the national PSM movement by engaging all its constituents in a synergistic collaboration.

Higher Education Institutions: Program Development

5. Higher education institutions should continue to innovate in and support the development of master's degree programs in the natural sciences to meet the needs of students seeking science-based careers and of the employers who hire them. PSM programs will provide students with deeper, often interdisciplinary, scientific knowledge and must include opportunities for the development of professional skills and practice through courses, summer internships, and business- or government-sponsored projects that provide an invaluable workplace experience. Providing incentives to and support for faculty to participate in these efforts, including program design and implementation, is critical.

Across higher education institutions with a wide array of missions and student populations, new programs have proven that master's education in the natural sciences focused on professional practice can benefit both students and employers. The further development of programs such as these is a major opportunity for both comprehensive and research institutions to contribute to national innovation and competitiveness.

Higher education institutions should continue to innovate in and support the development of master's degree programs in the natural sciences to meet the needs of students seeking science-based careers and of the local, regional, and national employers who hire them. Institutions should provide support from their own resources for these new, innovative programs. This support may be financial or in-kind in nature and should be coordinated with support from other sources, including

the federal government, state governments, philanthropic organizations, and employers. It will typically be necessary to develop new courses and curricula specific to each master's program and courses in professional practice that may be used by one or more programs. Institutions can be particularly effective by providing faculty with appropriate rewards and incentives for initiating and sustaining new industry-oriented master's programs. Finding a strong and respected "champion" within the faculty for a PSM program can add significantly to the establishment, development, and sustainability of a program.

PSM programs will provide students with deeper, more advanced scientific knowledge than is typically obtained in a four-year undergraduate program. This knowledge may focus on a specific field but may also be interdisciplinary in nature. Programs may be able to fuse scientific knowledge from one field with another, such as computer or information sciences, or integrate that knowledge with training in management, law, or public policy. In general, these programs should typically require two years to complete as a full-time student and must not be confused with master's degrees that are awarded along the student's successful or unsuccessful road to the Ph.D.

These programs must include courses or course elements focused on professional skills and practice in such areas as:

- Communication, interpersonal, and project management skills
- Teamwork, innovation, leadership, and entrepreneurship
- Business or public policy (economics, finance, management, organizational behavior)
- Legal climate
- Professional ethics
- Computation
- Culture/languages

Master's education in the sciences that consists solely of science courses provides only limited preparation for a career in business, government, or nonprofit organizations. Graduates benefit substantially from entrepreneurial and professional practice enhancements—a valuable addition that can help the graduate rapidly become a contributing employee.

Hands-on experience, very useful for students, is a key requirement of a PSM program. This may be provided through summer internships between the two program years. We also recommend business- or government-sponsored projects that provide an invaluable workplace experience—one that reinforces for the student the realities of the work world, the need for teamwork and communication, and how the science they are

learning is relevant. Graduates who present a portfolio of completed work sponsored by a business, government, or nonprofit organization and who have the business awareness and personal development that come from participating in these kinds of programs will find that their resumes stand out to employers.

Published educational and degree program standards and expectations play an important role in guiding higher education institutions to an appropriate balance of educational effort among bachelor's, master's, professional, and doctoral programs. For professional academic programs (like the PSM, as for those in medicine, engineering, law, etc.), universities and accrediting agencies should be attentive to the means by which such programs optimize their responsiveness to the needs of the professions for which they prepare graduates. The committee suggests that examination of reward and evaluation processes would promote awareness of the importance of PSM programs both to faculty work and to the nation's economic well-being.

Higher Education Institutions: Outreach

6. Higher education institutions should reach out to and work as partners with employers to create and sustain programs. The use of external employer advisory councils will provide substantive, real-time input for framing of new science master's programs and practical assistance with curriculum development, mentoring, marketing, employer-sponsored projects, internships, hiring for graduates, and financial support. Institutions should also provide outreach to students, informing undergraduate students and potential graduate students of the PSM degree opportunity.

Higher education institutions should reach out to and work as partners with employers to create and sustain programs. The creation and use of external employer advisory councils will provide critical input for framing of new science master's programs. Areas of interaction can include:

- Initial conception and scope of the degree program
- Curriculum development
- Mentoring
- Adjunct faculty
- Employer-sponsored projects
- Internships
- Employment
- Financial support

An innovative master's program that develops graduates for careers in business and industry will succeed only if a broad range of employers know about and value the program. This can be achieved to some extent by involving employers in the development and implementation of the masters program, but it also requires an effort by the university to market the program and make it known widely. Universities may be unaccustomed to this challenge or may find it difficult to market the program; they would likely benefit from guidance and support. A well-designed Internet site that relates the program to the interests of employers is one effective program-marketing tool. An ongoing effort to attend relevant business/industrial gatherings and talk about a program and its virtues is also important.

Institutions should provide outreach to students and recent alumni, informing undergraduate students and potential graduate students of the PSM degree opportunity. As a relatively new degree program and career track, many students have not been exposed to information about these programs and are unaware of the professional opportunities to continue in science that they afford. Faculty should be encouraged to recommend to advisees interested in non-research careers to consider PSM programs—even their best students whom they typically push in the direction of Ph.D. programs. Programs and institutions should also reach out to recent alumni, whose work experiences after graduation may additionally prepare them for PSM programs and the careers they lead to.

Employers

7. Employers in the for-profit, nonprofit, and government sectors should partner with higher education institutions to create and sustain PSM programs. They should participate on employer advisory councils through which they can assist with and benefit from program conception, curriculum development, mentoring, employer-sponsored projects, internships, employment, and financial support. They should invite representatives of PSM programs to speak at local or regional business gatherings that provide a forum for communication about the existence and attributes of PSM programs and their graduates. We encourage employers to broaden their recruiting beyond traditional sources to hire graduates from new programs. This includes not only federal agencies that require Ph.D.s for their world-class research centers, but also procurement officers, acquisition officials, project and program managers, and senior executives who, in their investment decision-making roles, must understand the latest in technology while simultaneously ensuring competitive business management outcomes. The PSM

provides an outstanding model for educating the individuals who can fill these important federal careers positions.

We encourage employers in the for-profit, nonprofit, and government sectors to partner with higher education institutions to create and sustain PSM programs. Employers may participate on program industry advisory councils. Through these and other channels, they can further assist with and benefit from:

- Initial conception and scope of the degree program
- Curriculum development
- Mentoring
- Adjunct faculty
- Employer-sponsored projects
- Internships
- Employment
- Financial support for programs or students

Master's education that is focused on preparing students for careers offers universities and business/industry a valuable opportunity to enrich and extend their existing relationships. This should be a particular concern for public universities, whose contributions to economic and workforce development are—appropriately—under close scrutiny. Working together to make master's programs relevant, current, and valuable provides universities and business/industry advisors with a powerful chance to learn from one another to the benefit of both. Employer input and participation are essential to creating master's programs whose graduates will be sought after by employers. They also provide an opportunity for employers with an opportunity to interact with a pool of well-trained, highly qualified master's-level professionals for future hires through internships and employer-sponsored projects and they have the opportunity to help shape their education and training through curriculum development.

The agency or organization providing the clearinghouse function should also provide outreach to current and potential employers. Many employers could benefit from hiring the graduates of a professional master's program, but they are not aware of the opportunities available to them. We also recommend that employers invite representatives of PSM programs to speak at local or regional business gatherings that provide a forum for communication about the existence and attributes of PSM programs and their graduates.

Lastly, we encourage employers to broaden their traditional recruiting to hire graduates from new programs. Many human resources (HR)

offices advertise and recruit based on existing—and sometimes out-of-date—job categories. These categories—or the notions of what credentials and skills these categories implicitly or explicitly contain—may not provide HR specialists with an awareness of PSM graduates and the distinctive backgrounds they bring. Hiring managers who become aware of PSM programs and graduates should communicate with HR offices in their firms, agencies, or organizations to ensure that recruitment efforts will include PSM graduates where appropriate.

Entrepreneurship within the American enterprise is not solely the domain of American industry. One must consider, as well, entrepreneurship within government. One needs only to look at the billions of dollars spent each year in the federal government on research and development and acquisition of material and complex devices. Several large mission agencies (Defense most notably, but also Energy, Commerce, Homeland Security, Health and Human Services, and NASA) make substantial investment decisions in material and sophisticated systems every day. These agencies are also technology performers in the national network of federal mission laboratories. While the government certainly requires its share of deeply trained Ph.D.s in the natural sciences to populate its world-class research centers, so too does it require procurement officers, acquisition officials, project managers, program managers, and senior executives who, in their investment decision-making roles, must understand the latest in the technology realm while simultaneously ensuring competitive business management outcomes. The PSM model fits perfectly with this extensive national need.

Students

8. Students in PSM degree programs should take full advantage of internships and industry-sponsored team projects. We encourage alumni to provide the professional programs from which they graduated with links to and resources from their current employers who can assist with mentoring, internship opportunities, and information about employment.

Students in PSM degree programs should take advantage of internships and industry-sponsored team projects. They provide opportunities to experience the application of what they are learning, reinforcing its relevance and deepening its meaning to the student. These activities also provide opportunities for the student to learn more about themselves, prospective employers, and the application of science. Finally, they may also involve international travel and work, which we believe to be extremely valuable in today's global work environment.

We encourage alumni to provide the professional programs from which they graduated links to and resources from their current employers, including mentoring, internship opportunities, and information about employment.

Appendixes

Appendix A

Charge to the Study Committee

The National Research Council will undertake a study exploring the role of master's education in the natural sciences and whether and how master's programs might be enhanced to bolster our workforce and our nation's science-based industries. The study committee will explore and answer, as possible given the data available, the following questions:

1. What are employer needs for staff trained in the natural sciences at the master's degree level? Are they able to find or develop the staff they need at this level?

2. How do employers communicate their employment needs to educational programs and how can this communication be enhanced?

3. What is known about students who pursue and obtain master's degrees in the natural sciences? What are their educational and career goals? How do master's programs meet or support these educational and career goals?

4. How do master's-level professionals in the natural sciences contribute in the workplace? What are the employee characteristics that employers seek in staff with advanced training? Do master's-level professionals enter the workforce with a master's degree or do they enter with a bachelor's degree and earn a master's degree later?

5. What can be learned from efforts already under way to reshape master's education in science? What effective practices have been identified that could be adopted by others? What can master's-level programs in the natural sciences learn from each other?

6. What can they learn from the way graduate-level professional programs in fields such as business, public policy, public health, and engineering developed to meet employer needs?

7. What findings and conclusions about appropriate goals and effective practices for enhancing master's education in the natural sciences can be drawn from the answers to the preceding questions?

8. What recommended next steps can the committee provide for stakeholders—students, faculty, department chairs, university administrators, employers, federal agencies and policymaking bodies—concerned with enhancing master's-level professional education?

Appendix B

Committee Member Biographies

RITA R. COLWELL, *Committee Chair*, is Chairman of Canon US Life Sciences, Inc. and Distinguished University Professor both at the University of Maryland at College Park and at Johns Hopkins University Bloomberg School of Public Health. Her interests are focused on global infectious diseases, water, and health, and she is currently developing an international network to address emerging infectious diseases and water issues, including safe drinking water for both the developed and developing world. Dr. Colwell served as the 11th Director of the National Science Foundation (NSF), 1998-2004. In her capacity as NSF Director, she served as Co-chair of the Committee on Science of the National Science and Technology Council. Her major interests include K-12 science and mathematics education, graduate science and engineering education, and the increased participation of women and minorities in science and engineering. Dr. Colwell has held many advisory positions in the U.S. government, nonprofit science policy organizations, and private foundations, as well as in the international scientific research community. She is a nationally respected scientist and educator, and has authored or co-authored 16 books and more than 700 scientific publications. She produced the award-winning film, *Invisible Seas*, and has served on editorial boards of numerous scientific journals. Before going to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute and Professor of Microbiology and Biotechnology at the University of Maryland. She was also a member of the National Science Board from 1984 to 1990. Dr. Colwell has previously served as Chairman of the Board of Governors

of the American Academy of Microbiology and also as President of the American Association for the Advancement of Science (AAAS), the Washington Academy of Sciences, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. Dr. Colwell is a 2006 National Medal of Science laureate and is a member of the National Academy of Sciences, the Royal Swedish Academy of Sciences, Stockholm, the American Academy of Arts and Sciences, and the American Philosophical Society. She has also been awarded 40 honorary degrees from institutions of higher education, including her Alma Mater, Purdue University. Dr. Colwell holds a B.S. in Bacteriology and an M.S. in Genetics from Purdue University, and a Ph.D. in Oceanography from the University of Washington.

DAVID S. CHAPMAN is professor of Geology & Geophysics and Dean of the Graduate School at the University of Utah. At Utah, Dr. Chapman has been a faculty member, department chair, Associate Dean of the Graduate School and now dean of the Graduate School and Associate Vice President for graduate studies. As graduate dean, Chapman implemented a tuition benefit for 2,000 graduate students, created a health insurance benefit for teaching and research assistants, and expanded training for international teaching assistants. In 2006, he was honored with the Rosenblatt Prize for Excellence, the University of Utah's most prestigious award. He has authored more than 120 publications, leads a research group studying thermal aspects of geological processes, and is immediate past chairman of the International Heat Flow Committee. In 2001, Chapman was elected to the Board of the Council of Graduate Schools (CGS), and in 2002, he was elected president of the Western Association of Graduate Schools. He has previously served on the U.S. National Committee for the International Union of Geodesy and Geophysics. Dr. Chapman received his B.S. in physics and mathematics in 1964 and his master's in physics in 1966 from the University of British Columbia. He received his Ph.D. in Geophysics from the University of Michigan.

JUNG CHOI is Associate Chair for the School of Biology, Associate Professor of Molecular Genetics, and Faculty Coordinator of the Bioinformatics Masters Degree Program at the Georgia Institute of Technology. His research focuses on plant molecular genetics and plant protein kinases. Dr. Choi has received numerous research grants as well as the honor of being a Lilly Endowment Teaching Fellow (1990-1991). He is a member of the AAAS and the Professional Science Masters Advisory Board for the CGS among other groups. Dr. Choi has his Ph.D. in Biology from the University of California San Diego (1983).

DARYL CHUBIN is the Director of the Center for Advancing Science and Engineering Capacity at the AAAS. He became Director in August 2004. Previously, he served as Senior Vice President for Research, Policy & Programs at the National Action Council for Minorities in Engineering (NACME) Inc. In addition, he spent nearly 15 years in federal service. His posts included Senior Policy Officer for the National Science Board at the NSF (1998-2001); Division Director for Research, Evaluation and Communication in NSF's Directorate for Education and Human Resources (1993-1998); and (on detail) Assistant Director for Social and Behavioral Sciences (and Education) at the White House Office of Science and Technology Policy (1997). Dr. Chubin has served on the faculty of four universities, including Georgia Tech, where he was promoted to full professor. He has published eight books and numerous reports on issues in science policy, human resource development, program evaluation, and engineering education. Among Dr. Chubin's honors are: AAAS Fellow, Past Chair of the AAAS section on Societal Impacts of Science and Engineering, Fellow of the Association for Women in Science, member of the National Academy of Engineering Committee on Diversity in the Engineering Workforce (as well as four other NRC committees), Integrator for BEST (Building Engineering and Science Talent), and co-recipient of the American Society of Engineering Education Wickenden Award for best paper published in the 2003 volume of *The Journal of Engineering Education*, Quality Education for Minorities/MSE 2006 Giant of Science, and Sigma Xi Distinguished Lecturer 2007-2009. Dr. Chubin earned his Ph.D. in sociology from Loyola University (Chicago) in 1973.

MARY E. CLUTTER is the former assistant director of the NSF where she was responsible for the Biological Sciences Directorate. Dr. Clutter has also served as the U.S. Chair of the U.S.-European Commission Task Force on Biotechnology and has been a member of the Board of Trustees of the International Human Frontiers Science Program, the Board of Regents of the National Library of Medicine, and the National Agricultural Research, Extension, Education and Economics Advisory Board. She served as chair of the Biotechnology Subcommittee of the Committee on Science of the National Science and Technology Council (NSTC), co-chair of the Subcommittee on Ecological Systems of the Committee on Environment and Natural Resources/NSTC and co-chair of the NSTC Committee on Science's Interagency Working Group on Plant Genomes. Dr. Clutter is a member of numerous professional societies and has served on the Board of Directors of the AAAS. She is a Fellow of the AAAS as well as of the Association for Women in Science. She is currently a member of the NRC's Policy and Global Affairs Committee. Dr. Clutter received her B.S. in

biology from Allegheny College and her master's and Ph.D. degrees from the University of Pittsburgh.

PAUL G. GAFFNEY II became the seventh president of Monmouth University in July 2003. President Gaffney, a retired Navy Vice Admiral, was president of the National Defense University from 2000 to 2003. Prior to that, he was the Chief of Naval Research with responsibility for science and technology investment, a substantial part of which supported basic research in American universities. He was appointed by President George W. Bush to the Ocean Policy Commission in July 2001, and served during its full tenure from 2001 to 2004. His naval career spanned over three decades including duty at sea, overseas, and ashore in executive and command positions. While a military officer, his career focused on oceanography, research administration, and education. President Gaffney is a 1968 graduate of the U.S. Naval Academy. Upon graduation, he was selected for immediate graduate education and received a master's degree in Ocean Engineering from Catholic University of America in Washington, D.C. He completed a year as a student and advanced research fellow at the Naval War College, graduating with highest distinction. He completed an M.B.A. at Jacksonville University. The University of South Carolina, Jacksonville University, and Catholic University have awarded him honorary doctorates. He has been recognized with a number of military decorations, the Naval War College's J. William Middendorf Prize for Strategic Research, the Outstanding Public Service Award from the Virginia Research and Technology Consortium, and the Potomac Institute's Navigator Award. He is a fellow of the American Meteorological Society, has served on several boards of higher education, and was a member of the Ocean Studies Board of the National Research Council during 2002-2004. He has been selected to be a Public Trustee for the New Jersey Marine Sciences Consortium and chaired the Governor's Commission to Protect and Enhance New Jersey's Military Bases, and serves on the Meridian Health Board of Trustees.

LEE L. HUNTSMAN is President Emeritus at the University of Washington (UW) and a Professor in the Department of Bioengineering. Before serving as President, he was UW's provost and vice president for academic affairs. His research interests are the mechanics of heart and heart muscle, cardiovascular system assessment, and new measurement techniques. In 2005, Dr. Huntsman was named executive director of the Life Sciences Discovery Fund Authority. Approved by the Washington state legislature, the fund uses tobacco settlement money to "help finance groundbreaking research and development of biomedical and other scientific advances." Dr. Huntsman is a fellow of the AAAS and the American Institute of Medical and Biological Engineering. From 2004 to 2005, he

served as a committee member on the “Committee To Assess the Capacity of the U.S. Engineering Research Enterprise” for the National Academy of Engineering. He received his Ph.D. in biomedical engineering from the University of Pennsylvania in 1968.

JONATHAN M. KAYES is a 24-year veteran of the Central Intelligence Agency. He has served as the CIA’s Chief Learning Officer since April 2006 and ran one of the CIA’s training centers from 2001 to 2004. He has spent the majority of his career in the Clandestine Service, splitting his assignments between the field and jobs at CIA HQS. While much of his work has focused on East Asia, he has also covered weapons proliferation, telecommunications, and terrorism. Mr. Kayes is a native of St. Louis where he attended the John Burroughs School. He graduated from Columbia University with a B.A. in political science. He also did master’s work at the Columbia School of International Affairs. Among other awards, CIA has awarded Mr. Kayes the Intelligence Commendation Medal and the Donovan Award.

DONALD N. LANGENBERG is Chancellor Emeritus of the 13-member University System of Maryland, having served as its head from 1990 to 2002. In 1983, Dr. Langenberg became Chancellor of the University of Illinois at Chicago where he was also a professor of physics. Dr. Langenberg has received countless honors and awards, and was named Deputy Director of the NSF by President Jimmy Carter in 1980. He was awarded the John Price Wetherill Medal of the Franklin Institute, the Distinguished Contribution to Research Administration Award of the Society of Research Administrators, and many others. Dr. Langenberg’s research has been primarily in experimental condensed matter physics and materials science. His work in this field of superconductivity led to a new type of voltage standard now in use worldwide. Dr. Langenberg serves or has served on many boards including the Board of Directors of the AAAS, of which he was Chairman; the Board of Directors of the Alfred P. Sloan Foundation; the Board of Trustees of the University of Pennsylvania; and the Executive Board of the National Association of the State Universities and Land Grant Colleges, of which he was Chairman. He was President of the American Physical Society, is Vice-Chairman of the board of the National Council for Science and the Environment, chairs the board of the Education Trust, Inc., and chairs the Professional Science Masters Advisory Board for the Council of Graduate Schools. In addition, Dr. Langenberg is currently a member of the Board of Trustees of the University of the District of Columbia, as well as a member of the NRC Committee on Teacher Preparation Programs in the U.S. Dr. Langenberg earned his B.S. at Iowa State University, his M.S. at the University of

California, Los Angeles, and his Ph.D. at the University of California, Berkeley. All of his degrees are in physics.

GEORGE LANGFORD is Dean of the College of Natural Sciences and Mathematics at the University of Massachusetts, Amherst. Before arriving at Amherst, Dr. Langford was the Ernest Everett Just Professor of Natural Sciences and professor of biological sciences at Dartmouth College in New Hampshire and an adjunct professor of physiology at the Dartmouth Medical Center from 1991 until 2005. He has numerous publications and his current laboratory work focuses on the neuronal cytoskeleton and the role actin plays in learning and memory. Dr. Langford was previously a National Institutes of Health (NIH) postdoctoral fellow at the University of Pennsylvania (1971-1973), an assistant professor of biology at the University of Massachusetts Boston (1973-1976), Josiah Macy Scholar at the Marine Biological Laboratory at Woods Hole, Massachusetts (1976), assistant professor of anatomy at the Howard University College of Medicine (1977-1979), and associate professor (1979-88) and professor (1988-1991) of physiology in the School of Medicine at the University of North Carolina at Chapel Hill. Dr. Langford has been an NIH grantee (1978-1986) and program director for the NSF's cell biology program (1988-1989). From 1998 to 2004, he served on the National Science Board. He has served on several NRC committees and currently is a member of NRC's Associateship and Fellowship Programs Advisory Committee. Dr. Langford received his Ph.D. in cell biology from the Illinois Institute of Technology and was a postdoctoral fellow at the University of Pennsylvania.

HENRY RIGGS became founding President of the Keck Graduate Institute of Applied Life Sciences in March 1997 following nine years as President and Professor of Engineering of Harvey Mudd College. Both of these institutions are members of the Claremont Colleges Consortium. He retired as president on July 15, 2003. Earlier, he was Stanford's Vice President for Development, heading all university fundraising activities, and remains the Thomas Ford Professor of Engineering Management, Emeritus. Professor Riggs has specialized in engineering management with a focus on industrial finance and control, managing technical companies, and new enterprise management. He taught control and management courses at Stanford's School of Engineering and a course in the management of technology jointly with the Graduate School of Business. His commitment to teaching is evidenced by his receipt of the Tau Beta Pi Award for Excellence in Undergraduate Engineering Teaching in 1979 and the Walter J. Gores Faculty Achievement Award in 1980. He has a B.S. degree from Stanford and an MBA degree from Harvard and honorary doctoral degrees from Harvey Mudd College (2006) and Keck Graduate Institute

(2007). He has held business positions with Ampex (1957-1958), Stanford Research Institute (1960-1963), Icore Industries (1963-1970), and Measurex (1970-1974). From 1965 to 1970, he was president of Icore; from 1970 to 1974, he was vice president of finance at Measurex. He taught at Stanford from 1970 to 1988 and was chairman of the Department of Industrial Engineering and Engineering Management from 1978 to 1982. He is currently a director of several companies and the author of several books.

JIM SPOHRER is the Director of Almaden Services Research, with the mission of creating and deploying service innovations that matter and scale well both internally to transform IBM and externally to transform IBM client capabilities (“double win” service innovations). Service system innovation is a multidisciplinary endeavor, integrating technology, business model, social-organizational, and demand innovations (just think about the ubiquity of credit cards, and what it took to make that service system innovation global; also, too often, people focus on the invention of the light bulb, and forget about the service system innovations required to make that point technology innovation beneficial to so many). Prior to joining IBM, Spohrer was at Apple Computer, attaining the role of Distinguished Scientist, Engineer, and Technologist for his pioneering work on intelligent multimedia learning systems, next generation authoring tools, on-line learning communities, and augmented reality learning systems. He has published in the areas of speech recognition, artificial intelligence, empirical studies of programmers, next generation learning systems, and service science. Spohrer graduated with a Ph.D. in computer science from Yale University (specializing in artificial intelligence and cognitive science) in 1989 and a B.S. in physics from MIT in 1978.

RICHARD TAPIA [NAE] is University Professor, Maxfield-Oshman Professor in Engineering, Director of the Center for Excellence and Equity in Education, and Associate Director of Graduate Studies at Rice University. A mathematician and professor in the Department of Computational and Applied Mathematics at Rice, Dr. Tapia is known for both his research and leadership in education and outreach programs. At Rice, Dr. Tapia directs the institution’s NSF-funded Alliance for Graduate Education in the Professoriate program which provides opportunities for undergraduate and graduate students in science, mathematics, and engineering to participate in university activities and work for the summer under the guidance of researchers at Rice. Due to his efforts, Rice has received national recognition for its educational outreach programs and the Rice Computational and Applied Mathematics Department has become a national leader in producing women and underrepresented minority Ph.D. recipients in the mathematical sciences. Dr. Tapia is the recipient of the Society for

Industrial and Applied Mathematics (SIAM) Prize for Distinguished Service to the Profession, the American Mathematical Society Distinguished Public Service Award, NACME's Reginald H. Jones Distinguished Service Award, the SACNAS Distinguished Scientist Award, the Lifetime Mentor Award from the American Association for the Advancement of Science, and the 1996 Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. Dr. Tapia has also been named Hispanic Engineer of the Year by Hispanic Engineer Magazine and was awarded the inaugural A. Nico Habermann Award by the Computer Research Association in 1994. Dr. Tapia has previously served on the National Science Board. He has been a member of the National Academy of Engineering since 1992 and served as chair of the NRC's Board on Higher Education and Workforce from 2001 to 2004. He received his B.A., M.A., and Ph.D. degrees in mathematics from the University of California-Los Angeles.

THOMAS R. TRITTON served as Haverford College's twelfth president and was a cancer chemotherapy research expert whose work was continuously funded by the American Cancer Society and the NIH. He is currently the President-in-Residence at the Harvard Graduate School of Education and will become president of the Chemical Heritage Foundation in 2008. A past deputy director of the Vermont Comprehensive Cancer Center—a Designated Center of the National Cancer Institute—Tritton is a member of the American Association for Cancer Research and the American Society of Biological Chemistry and Molecular Biology. In 1987 he co-chaired the first international symposium on organ-directed toxicities of cancer drugs, and the following year he chaired the Gordon Research Conference on cancer chemotherapy, an annual meeting of 135 prominent cancer specialists. Tritton has also served on the American Association of Cancer Research Program Committee and the board of directors of the Vermont Technology Council. From 1973 to 1975 he was a postdoctoral fellow in Yale's Chemistry Department. For the next 10 years he was an assistant and associate professor of pharmacology at Yale until joining the pharmacology faculty at the University of Vermont in 1985. As vice provost at the University of Vermont from 1991 to 1997, Tritton was the senior research officer there, directing all aspects of sponsored programs, facilities, research funding, outreach, technology, and research policy for the university. In that position he also oversaw all computing and information technology, as well as university arts programs, including the Fleming Museum, the largest fine arts museum in Vermont.

PHILIP TUCHINSKY is an applied mathematician, recently retired from a 28-year career at Ford Motor Company Research & Advanced Engi-

neering. In the final decade of his varied career, Tuchinsky helped create Ford's first data mining group within a larger business intelligence (BI) effort (which Ford calls systems analytics). This BI organization, today about twenty strong, functions as a consulting group that conducts research for company operations (its customers). The BI practice proved very successful and grew steadily over the decade. It has gained a reputation that extends to very senior executives and throughout industry. As a data miner, Tuchinsky developed a specialty in innovative warranty analysis. He has also worked with SIAM and several Michigan universities to encourage the growth of these technologies by creating conferences and other events. Highlights of his Ford career include Henry Ford Technology Awards in 1985 and 2000. His career record includes hundreds of internal and external publications and presentations. Tuchinsky's retirement interests include consulting as the owner of Tuchinsky BI, LLC. Since 2002, masters-level education in the sciences has been an important personal and professional interest. He serves as an industrial advisor to the professional sciences masters (PSM) degree program in Industrial Mathematics at Michigan State University. He has spoken by invitation about the business significance of PSM degrees and the value of hiring PSM graduates in many forums. Tuchinsky serves on the Advisory Board of the Council of Graduate Schools PSM program. He is also participating in the development of a pioneering PSM program at the University of Michigan: an M.S. in Applied Complex Systems. Dr. Tuchinsky won a Woodrow Wilson Fellowship for graduate study as he completed a mathematics major at Queens College, CUNY in 1966. He completed his M.S. and Ph.D. degrees at the Courant Institute of Mathematical Sciences, New York University, in 1968 and 1971.

Appendix C

Committee Meeting Agendas

Meeting One
Keck Center of the National Academies
500 Fifth Street, NW, Washington, DC 20001
March 28-29, 2007
Open Session Agenda

Wednesday, March 28, 2007, Room 201

- 9:30 **Welcome**
Rita Colwell, Committee Chair
- 9:35 **Perspective from Sponsor and Discussion of Charge**
Michael Teitelbaum, Vice President, Alfred P. Sloan Foundation
- 10:00 Break
- 10:15 **Master's Education in the United States**
Judith Glazer-Raymo, Lecturer and Fellow, Teachers College,
Columbia University; author of *Professionalizing Graduate
Education: The Master's Degree in the Marketplace*
- 11:15 **Professional Science Master's Degree**
Carol Lynch, Senior Scholar in Residence and Director of the
PSM Initiative, Council of Graduate Schools
- 12:15 Lunch will be provided in the meeting room

1:00 Developments in the Life and Physical Sciences

Keck Graduate Institute of Applied Life Sciences
Henry Riggs, President Emeritus, Keck Graduate Institute of the Applied Life Sciences

The Master's Degree in Physics
Roman Czujko, Director, Statistical Research Center, American Institute of Physics; co-author of *Programs that Match Every Interest: Master's Degree in Physics*

2:15 Break

2:30 Demand for and Supply of Science Master's Degree Recipients

An Industry Perspective of the PSM Degree in California
M. Daniel DeCillis, Research Associate, California Council on Science and Technology

Data on Master's Education in Science and Mathematics
Nathan Bell, Associate Director, Commission on Professionals in Science and Technology

3:45 Committee Discussion

Rita Colwell, Committee Chair
Discussion of presentations
Looking towards the final report: Issues, Evidence, Outline

5:00 Adjourn day one

Thursday, March 29, 2007, Room 206*Open Session***8:30 IBM and Service Science**

Jim Spohrer, Director of Services Research, IBM Almaden Research Center

9:15 Break

- 9:30 **Next Steps**
Peter Henderson, Study Director
Review of Work Plan
Summer Workshop/Meeting: Agenda and Speakers

- 11:00 **Adjourn**

Meeting Two
Keck Center of the National Academies
500 Fifth Street, NW, Washington, DC 20001
July 14-16, 2007
Open Session Agenda

Saturday, July 14, 2007, Room 100

- 8:30 **Welcome**
Rita Colwell, Committee Chair
- 8:45 **The Master's Degree in Context: Higher Education and Competitiveness Policy**
James Duderstadt, President Emeritus and University Professor of Science and Engineering, University of Michigan (via teleconference)

Alan Merten, President, George Mason University
- 10:00 **Master's Education: Government Perspective**
Cora Marrett, Associate Director for Education and Human Resources, National Science Foundation
- 10:45 Break
- 11:00 **University Response to Changes in Master's Education**
Gary Reichard, Executive Vice Chancellor, California State University System

Alan Mabe, Vice President for Academic Planning and University-School Programs, University of North Carolina
- 12:00 Lunch
- 1:00 **Who Earns Masters Degrees in the Natural Sciences and What Do They Do?**
Mark Regets, Senior Analyst, Science Resources Statistics, National Science Foundation

- 1:45 **Masters Education: Graduate Deans**
David Chapman, Dean of the Graduate School, University of Utah
- Karen Klomparens, Dean, Graduate School, Michigan State University
- 2:45 Break
- 3:00 **Perspective of PSM Program Directors**
Linda Strausbaugh, Professor of Genetics, Director, Center for Applied Genetics and Technology, and Co-Director, Professional Science Masters Program, University of Connecticut
- Bogdan Vernescu, Chair, Department of Mathematical Sciences, and Program Director; PSM Programs in Industrial Mathematics and Financial Mathematics, Worcester Polytechnic Institute
- 4:00 **PSM Program Directors: Bioinformatics**
William Detrich, PSM Program Director, Bioinformatics, Northeastern University
- Jung Choi, PSM Program Director, Bioinformatics, Georgia Institute of Technology

Sunday, July 15, 2007, Room 110

- 9:00 **Workforce Demand: Intelligence Community**
Stephen Willar, Director, S&T Recruitment, Central Intelligence Agency
- 9:45 **Workforce Demand: Modeling and Business Intelligence**
Philip Tuchinsky, Technical Expert, Systems Analytics Research Group, Ford Motor Company Research & Advanced Engineering (retired)

Monday, July 16, 2007, Room 110

- 9:00 **Skills for the 21st Century**
Margaret Hilton, Center for Education, The National Academies
- 9:45 **University Response to Changes in Master's Education**
Susan Aldridge, President, University of Maryland University College

Appendix D

America COMPETES Act¹, Section 7034: Provisions for Professional Science Master's Program

SEC. 7034. PROFESSIONAL SCIENCE MASTER'S DEGREE PROGRAMS.

(a) CLEARINGHOUSE.—

(1) DEVELOPMENT.—The Director shall establish a clearinghouse, in collaboration with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, to share program elements used in successful professional science master's degree programs and other advanced degree programs related to science, technology, engineering, and mathematics.

(2) AVAILABILITY.—The Director shall make the clearinghouse of program elements developed under paragraph (1) available to institutions of higher education that are developing professional science master's degree programs.

(b) PROGRAMS.—

(1) PROGRAMS AUTHORIZED.—The Director shall award grants to 4-year institutions of higher education to facilitate the institutions' creation or improvement of professional science master's degree programs that may include linkages between institutions of higher edu-

¹America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, Public Law No. 110-69.

cation and industries that employ science-trained personnel, with an emphasis on practical training and preparation for the workforce in high-need fields.

(2) APPLICATION.—A 4-year institution of higher education desiring a grant under this section shall submit an application to the Director at such time, in such manner, and accompanied by such information as the Director may require. The application shall include—

(A) a description of the professional science master's degree program that the institution of higher education will implement;

(B) a description of how the professional science master's degree program at the institution of higher education will produce individuals for the workforce in high-need fields;

(C) the amount of funding from non-Federal sources, including from private industries, that the institution of higher education shall use to support the professional science master's degree program; and

(D) an assurance that the institution of higher education shall encourage students in the professional science master's degree program to apply for all forms of Federal assistance available to such students, including applicable graduate fellowships and student financial assistance under titles IV and VII of the Higher Education Act of 1965 (20 U.S.C. 1070 et seq., 1133 et seq.).

(3) PREFERENCES.—The Director shall give preference in making awards to 4-year institutions of higher education seeking Federal funding to create or improve professional science master's degree programs, to those applicants—

(A) located in States with low percentages of citizens with graduate or professional degrees, as determined by the Bureau of the Census, that demonstrate success in meeting the unique needs of the corporate, non-profit, and government communities in the State, as evidenced by providing internships for professional science master's degree students or similar partnership arrangements; or

(B) that secure more than two-thirds of the funding for such professional science master's degree programs from sources other than the Federal Government.

(4) NUMBER OF GRANTS; TIME PERIOD OF GRANTS.—

(A) NUMBER OF GRANTS.—Subject to the availability of appropriated funds, the Director shall award grants under paragraph (1) to a maximum of 200 4-year institutions of higher education.

(B) TIME PERIOD OF GRANTS.—Grants awarded under this section shall be for one 3-year term. Grants may be renewed only once for a maximum of 2 additional years.

(5) EVALUATION AND REPORTS.—

(A) DEVELOPMENT OF PERFORMANCE BENCHMARKS.—Prior to the start of the grant program, the Director, in collaboration with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, shall develop performance benchmarks to evaluate the pilot programs assisted by grants under this section.

(B) EVALUATION.—For each year of the grant period, the Director, in consultation with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, shall complete an evaluation of each program assisted by grants under this section. Any program that fails to satisfy the performance benchmarks developed under subparagraph (A) shall not be eligible for further funding.

(C) REPORT.—Not later than 180 days after the completion of an evaluation described in subparagraph (B), the Director shall submit a report to Congress that includes—

- (i) the results of the evaluation; and
- (ii) recommendations for administrative and legislative action that could optimize the effectiveness of the pilot programs, as the Director determines to be appropriate.

Appendix E

Estimating the Path of Master's Degree Recipients in the Biological Sciences

Annually, U.S. institutions award 1.3 master's degrees in the biological sciences for each doctorate awarded in that field. For example, there were about 7,800 master's and almost 6,000 Ph.D.s awarded by U.S. institutions in the biological sciences in 2004. We can examine the national data further to better understand the pathways of graduate students through master's and doctoral programs to careers.

On average, the time-to-degree for new doctorates in the biological sciences was 6.7 years in 2004. About 40 percent, or 2,400 of the 6,000 new Ph.D.s, had earned a master's degree en route. Assuming, then, that these students started graduate study in 1997 and those who were awarded the master's degree received it in 1999 (after two years of study), then about 4,400 of the nearly 6,800 master's recipients in the biological sciences that year (1999) earned a master's degree and did not continue to the doctorate. However, we know from National Science Foundation data that only about 55%, or 3,700, of master's degree holders in the biological sciences earn no further degrees. This suggests that of the 4,400 who earned a master's degree and no doctorate, about 700 earned some other advanced degree.

In sum, then, we have four groups of students: (1) 3,700 who earned the master's degree and no other degree; (2) 700 who earned a master's degree and an advanced degree other than the doctorate (medicine, law, business, etc.); (3) 2,400 who earned a master's, mainly as a stepping-stone

to the doctorate; and (4) 3,600 who earned only a doctorate.¹ There are no data sources that will allow us to tease out, for the biological sciences, how many of those who earned only a master's degree intended to earn just that degree and how many had hoped to go on to a doctorate.

¹T. B. Hoffer et al., *Doctorate Recipients from United States Universities: Summary Report 2004* (Chicago: National Opinion Research Center). The report gives the results of data collected in the Survey of Earned Doctorates, conducted for six federal agencies—NSF, NIH, USED, NEH, USDA, and NASA—by NORC. The SED reports 5,937 Ph.D.s in the biological sciences in 2004, 703 of which were in biochemistry. Biochemists had a time-to-degree of 6.1 years, and 31.25 reported having a master's degree. Other Ph.D.s in the biological sciences had a time-to-degree of 6.7 years, and 40.3 percent had master's degrees. Number of master's degrees in the biological sciences is from the National Center for Education Statistics, Digest of Education Statistics 2006, Table 255, http://nces.ed.gov/programs/digest/d06/tables/dt06_255.asp (accessed October 26, 2007).

Appendix F

Development of Selected Professional Degree Programs

In the development of professional-focused master's education in business, public administration/policy, public health, and other professional fields, and in the development of medical education as well, several patterns can be observed across fields.

- A single pioneering institution initiated a master's program in the field.
- Philanthropy in the form of early funding consistently played a key role.
- After the field had matured, a report that took an overall view of the emerging field, made conclusions about how to organize/rationalize the field and its programs in response to the societal needs, and then had a significant impact through its implementation.
- The field continued to evolve in response to social and economic factors.

Philanthropy's role as a catalyst is of particular note. Philanthropic organizations not only provided early funding to launch programs but also played a role in funding studies whose reports had an impact on the future development of the field. The Flexner Report (1910), which had such a significant impact on medical education, was both initiated and funded by the Carnegie Foundation for the Advancement of Teaching. Similarly, Higher Education for Business (1959)—funded by the Ford Foundation—and the Education of American Businessmen (1959)—funded by Carnegie—also had significant impacts on business education and the master in business administration in particular.

TABLE F-1 Development of Selected Professional Degree Programs

| | M.D. | M.B.A. | M.P.A./M.P.P. | M.P.H. |
|---------------------------------------|--|--|--|---|
| Origins (Date/institution) | In 1765, Drs. John Morgan and William Shippen, Jr., founded the Medical School of the College of Philadelphia, the first medical school in North America | 1881 at the Wharton School at the University of Pennsylvania Harvard Business School (1908) was first to require a university degree for entry | 1936 Gift from Lucius Littauer to create Graduate School of Public Administration at Harvard. Later evolves into John F. Kennedy School of Government in 1970s | 1916 Johns Hopkins Bloomberg School of Public Health |
| | In the 19th century, the U.S. medical education was non-standard and frequently inadequate, being administered through 1 of 3 basic systems: an apprenticeship system, proprietary schools, university-based education | | Public management program at the University of Maine in 1945 Late 1950s establishment of Maxwell School at Syracuse University | |
| Influential reports | Flexner Report (1910, funded by Carnegie Foundation for the Advancement of Teaching) addressed the need for standardization and quality in medical education | “Higher Education for Business” by Gordon and Howell (1959, funded by Ford) “The Education of American Businessmen” by Pierson (1959, funded by Carnegie) | Ward Stewart report of 1961 Donald Stone’s report on “The Response of Higher Education to the Needs of Public Service” in 1971 | Institute of Medicine report on “The Future of Public Health” from 1988 |

| | | | | | |
|---|---|--|---|---|---|
| External trends influencing evolution of degree | Scientific breakthroughs in medicine supported calls for standardization in medicine | These reports addressed business schools' "vocationalism and mediocrity" | Scientific management studies throughout the 20th century (e.g., Taylorism; Six Sigma); competition with Japan in the early 1980s | The Great Society; professionalization of public service | Spread of communicable diseases; disparity in health care outcomes across socioeconomic levels and countries; politicization of health care |
| Role of external stakeholders | The AMA sought to eliminate schools that failed to adopt a rigorous brand of systematized, experiential medical education | Ford and Carnegie Foundations funded reports in late 1950s; variety of "in-house" corporate programs (e.g., Motorola U.) | Federal recognition through fellowships in 1968 HEA reauthorization; Intergovernmental Personnel Act; Presidential Management Internship Program; Truman Scholarships | Generally two years | Generally two years |
| Duration of program | Four years | Generally two years | Joint programs are commonly available with law, public policy, business, and other MA programs | Joint programs are commonly available with law and other MA programs | Joint programs are commonly available with medicine, law, public policy, business |
| Joint programs | Joint programs are commonly available with public health (MPH) or biomedical research (Ph.D.) | Joint programs are commonly available with law, public policy, business, and other MA programs | Joint programs are commonly available with law and other MA programs | Joint programs are commonly available with medicine, law, public policy, business | Joint programs are commonly available with medicine, law, public policy, business |
| Testing | MCAT | GMAT | GRE | GRE; MCAT (for joint MD/MPH programs) | GRE; MCAT (for joint MD/MPH programs) |

TABLE F-1 Continued

| | M.D. | M.B.A. | M.P.A./M.P.P. | M.P.H. |
|---------------------------|--|---|---|--|
| Standards | State licensing boards require high admissions standards and strict curriculum requirements | Specific standards identified for three areas: strategic management; participants (students and faculty); and assurance of learning | Under revision for 2009; current standards address nine areas: program eligibility; mission; jurisdiction; curriculum; faculty; student admissions; student services; support services; off-campus and distance education | |
| Specialized accreditation | Liaison Committee on Medical Education (LCME) | Five-year cycle; Application, followed by consultation with appointed mentor, followed by site visit coordinated by Association to Advance Collegiate Schools of Business (AACSB) | Seven-year cycle; Self-study followed by site visit coordinated by National Association of Schools of Public Affairs and Administration (NASPAA) | Seven-year cycle; Self-study followed by site visit coordinated by Council on Education for Public Health |
| Disciplinary affiliations | Preclinical: Anatomy, biochemistry, physiology, pharmacology, histology, embryology, microbiology, pathology, neuroscience | Economics; sociology; accounting; marketing; finance | Political science; economics; sociology | Health services administration; biostatistics; epidemiology; behavioral sciences/health education; environmental health services |

| | | | | |
|---|--|---|--|---|
| Organizational affiliations | Clinical: internal medicine, surgery, pediatrics, family medicine, obstetrics/ gynecology, neurology, psychology American Association of Medical Colleges | AACSB (1916-present) | Council on Graduate Education for Public Administration (late 1950s-1970); NASPAA (1970-present) | Association for Schools of Public Health (1953-present) |
| International variations/ exportability | Exported to Europe during the 20th century; INSEAD offered first European MBA in 1957 | Influenced establishment of Association of Schools of Public Health in the European Region (1966) | | |

SOURCES: Glazer-Raymo, *Professionalizing Graduate Education*. Conrad et al., *A Silent Success*.

Appendix G

Side-by-Side Comparison:
Keck Graduate Institute of the Applied
Life Sciences,
Sloan Foundation Professional
Science Master's Initiative,
and America COMPETES Act,
Section 7034 PSM Provisions

| | |
|--------------------------------------|--|
| Program Feature | Keck Graduate Institute of Applied Life Sciences |
| Participating Institutions | KGI was established as an independent graduate institute within the Claremont Colleges Consortium. |
| Industry/Employer Involvement | <p>The KGI Board of Trustees and Advisory Council includes representatives of industry, particularly in biotechnology.</p> <p>One employer, Amgen, has hired about 20% of KGI graduates.</p> <p>The MBS program includes a summer internship between the two years.</p> <p>The curriculum also includes a team master's project, typically funded on a project-by-project basis by private firms at \$50,000 each.</p> |
| Program Characteristics | <p>(1) The Master of Bioscience (MBS) program focuses on biosciences—more specifically biotechnology, pharmaceutical, healthcare product, and bioagricultural fields.</p> <p>(2) The MBS curriculum is approximately 2/3 science and engineering and 1/3 management and ethics. The program includes a Team Masters Project each funded by a private sponsor and focused on a real-world problem.</p> |

Alfred P. Sloan Foundation
Professional Science Master's
Initiative

PSM Provisions of the
American COMPETES Act

Sloan initially provided \$125,000 per institutional program track for startups in research universities. Later, as there was accumulated knowledge as to how to launch a PSM track, the amount per program dropped to \$90-\$100,000. Still, later, when the Master's granting institutions were competing, the amount per program was \$40,000 per track.

The NSF Director shall award grants to 4-year institutions of higher education to facilitate the institutions' creation or improvement of professional science master's degree programs.

Programs typically have industry advisory boards.

Programs may include linkages between institutions of higher education and industries that employ science-trained personnel.

Programs see potential employers as industry, government agencies, and nonprofits.

Programs are required to have a summer internship.

(1) Fields in the physical sciences, biological sciences, mathematics, and computer science. A particular effort was made to identify 12 bioinformatics programs. The scientific focus of a program track was identified by the institution. Very often they are interdisciplinary in nature.

(1) Programs should focus on high-need fields.

(2) PSM programs include a "plus" component that focuses on workplace skills: communication, project management, interdisciplinary teamwork, ethics, and—as appropriate—business, legal, or computational skills.

(2) Programs should have an emphasis on practical training and preparation for the workforce.

| | |
|---------------------------|--|
| Program Feature | Keck Graduate Institute of Applied Life Sciences |
| Program Funding | The W.M. Keck Foundation provided an initial funding of \$50 million (current use and endowment) to establish KGI. An additional \$20 million grant from Keck and \$30 million from other sources has been invested. |
| Number of Programs | Master of Bioscience Program (2 years). New Fully Employed Master of Bioscience Program (for full-time employees; delivered via distance learning and evening classes; 3 year program). |
| Time Period | N/A |

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Sloan grant funds approved for PSM programs (from 1/1/1997 to present): \$17.5 million. Sloan grant funds paid out to date: \$15.9 million. This includes grants to institutions, and other grants to university systems, CGS, CPST, science societies, and other organizations that promoted the PSM.
More than 100 program tracks in 50 institutions across 20 states as a result of Sloan’s funding 1997-2007.

The COMPETES Act authorizes funding for NSF to implement Section 7034 at up to \$10 million for FY 2008, \$12 million in FY 2009, and \$15 million in FY 2010.

Subject to the availability of appropriated funds, the Director shall award grants to a maximum of 200 4-year institutions of higher education.

Grants to research institutions were for 3 years. Almost all requested NCEs. Average total grant period of about 5 years.

Grants awarded under this section shall be for one 3-year term. Grants may be renewed only once for a maximum of 2 additional years.

Later, planning grants of \$7,000 were provided to master’s focused institutions so they could prepare applications for one year grants.

| | |
|----------------------------|---|
| Program Feature | Keck Graduate Institute of Applied Life Sciences |
| Program Application | N/A |

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Programs are required to have the following:

- a) presence of an employer advisory group,
- b) availability (requirement) of "plus" courses in business basics, ethics, patent law, regulatory affairs, etc.,
- c) internship,
- d) 70% of course time in science (with interdisciplinarity).

A 4-year institution of higher education desiring a grant under this section shall submit an application to the Director at such time, in such manner, and accompanied by such information as the Director may require. The application shall include—

- (A) a description of the professional science master's degree program that the institution of higher education will implement;
- (B) a description of how the professional science master's degree program at the institution of higher education will produce individuals for the workforce in high-need fields;
- (C) the amount of funding from non-Federal sources, including from private industries, that the institution of higher education shall use to support the professional science master's degree program; and
- (D) an assurance that the institution of higher education shall encourage students in the professional science master's degree program to apply for all forms of Federal assistance available to such students, including applicable graduate fellowships and student financial assistance under titles IV and VII of the Higher Education Act of 1965 (20 U.S.C. 1070 et seq., 1133 et seq.).

Program Feature Keck Graduate Institute of
Applied Life Sciences

Preferences

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American COMPETES Act

Sloan gave initial preference to research institutions. Later, the program was expanded to include other doctorate granting institutions and master's focused institutions.

The Director shall give preference in making awards to institutions seeking Federal funding to create or improve professional science master's degree programs, to those—

(A) located in States with low percentages of citizens with graduate or professional degrees, as determined by the Census Bureau, that demonstrate success in meeting the unique needs of the corporate, non-profit, and government communities in the State, as evidenced by providing internships for professional science master's degree students or similar partnership arrangements; or

(B) that secure more than two-thirds of the funding for such professional science master's degree programs from sources other than the Federal Government.

| | |
|---------------------------|---|
| Program Feature | Keck Graduate Institute of Applied Life Sciences |
| Program Evaluation | Regional institutional accreditation (Western Association of Schools and Colleges). |

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PSM Provisions of the
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No formal evaluation program
required.

(A) DEVELOPMENT OF PERFORMANCE BENCHMARKS.—Prior to the start of the grant program, the Director, in collaboration with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, shall develop performance benchmarks to evaluate the pilot programs assisted by grants under this section.

(B) EVALUATION.—For each year of the grant period, the Director, in consultation with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, shall complete an evaluation of each program assisted by grants under this section. Any program that fails to satisfy the performance benchmarks developed under subparagraph (A) shall not be eligible for further funding.

(C) REPORT.—Not later than 180 days after the completion of an evaluation described in subparagraph (B), the Director shall submit a report to Congress that includes—(i) the results of the evaluation; and (ii) recommendations for administrative and legislative action that could optimize the effectiveness of the pilot programs, as the Director determines to be appropriate.

| Program Feature | Keck Graduate Institute of Applied Life Sciences |
|----------------------|--|
| Clearinghouse | Extensive and expensive recruitment of applicants. |

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American COMPETES Act

Sciemasters.com has provided clearinghouse of information on PSM programs. With funding from the Sloan Foundation, this site was maintained by Sheila Tobias, 1997-2006, and by CGS, 2006-present.

A new association of PSM directors, the National PSM Association (NPSMA), has formed in 2007. This association will also serve as a clearinghouse of information about PSM programs.

(1) The NSF Director shall establish a clearinghouse, in collaboration with 4-year institutions of higher education (including applicable graduate schools and academic departments), and industries and Federal agencies that employ science-trained personnel, to share program elements used in successful professional science master's degree programs and other advanced degree programs related to science, technology, engineering, and mathematics.

(2) The NSF Director shall make the clearinghouse available to institutions of higher education that are developing professional science master's degree programs.

Appendix H

Data Tables

TABLE H-1 Master's Degrees and Doctorates Conferred, by Sex of Student and Field of Study: 2004-2005

| Field of Study | Master's degrees | | Doctor's degrees (Ph.D., Ed.D., etc.) | | | |
|--|------------------|---------|---------------------------------------|--------|--------|--------|
| | Total | Male | Female | Total | Male | Female |
| All fields, total | 574,618 | 233,590 | 341,028 | 52,631 | 26,973 | 25,658 |
| Agriculture and natural resources | 4,746 | 2,288 | 2,458 | 1,173 | 763 | 410 |
| Architecture and related services | 5,674 | 3,180 | 2,494 | 179 | 110 | 69 |
| Area, ethnic, cultural, and gender studies | 1,755 | 669 | 1,086 | 189 | 81 | 108 |
| Biological and biomedical sciences | 8,199 | 3,318 | 4,881 | 5,578 | 2,845 | 2,733 |
| Business, management, marketing, and services | 142,617 | 82,151 | 60,466 | 1,498 | 901 | 597 |
| Communication and communications technologies | 7,195 | 2,535 | 4,660 | 468 | 195 | 273 |
| Computer and information sciences and services | 18,416 | 13,136 | 5,280 | 1,119 | 905 | 214 |
| Education | 167,490 | 38,863 | 128,627 | 7,681 | 2,557 | 5,124 |
| Engineering and engineering technologies | 35,133 | 27,161 | 7,972 | 6,601 | 5,368 | 1,233 |
| English language and literature/letters | 8,468 | 2,615 | 5,853 | 1,212 | 494 | 718 |
| Family and consumer sciences/human sciences | 1,827 | 229 | 1,598 | 331 | 68 | 263 |
| Foreign languages, literatures, and linguistics | 3,407 | 1,056 | 2,351 | 1,027 | 410 | 617 |
| Health professions and related clinical sciences | 46,703 | 9,816 | 36,887 | 5,868 | 1,710 | 4,158 |
| Legal professions and studies | 4,170 | 2,304 | 1,866 | 98 | 58 | 40 |

| | | | | | | |
|--|--------|-------|--------|-------|-------|-------|
| Liberal arts, general studies, and humanities | 3,680 | 1,381 | 2,299 | 109 | 38 | 71 |
| Library science | 6,213 | 1,241 | 4,972 | 42 | 14 | 28 |
| Mathematics and statistics | 4,477 | 2,525 | 1,952 | 1,176 | 841 | 335 |
| Military technologies | 0 | 0 | 0 | 0 | 0 | 0 |
| Multi-/interdisciplinary studies | 4,252 | 1,440 | 2,812 | 983 | 440 | 543 |
| Parks, recreation, leisure, and fitness studies | 3,740 | 1,935 | 1,805 | 207 | 119 | 88 |
| Philosophy and religious studies | 1,647 | 995 | 652 | 586 | 418 | 168 |
| Physical sciences and science technologies | 5,678 | 3,457 | 2,221 | 4,114 | 2,966 | 1,148 |
| Precision production | 6 | 1 | 5 | 0 | 0 | 0 |
| Psychology | 18,830 | 3,900 | 14,930 | 5,106 | 1,466 | 3,640 |
| Public administration and social service professions | 29,552 | 7,370 | 22,182 | 673 | 272 | 401 |
| Security and protective services | 3,991 | 1,974 | 2,017 | 94 | 55 | 39 |
| Social sciences and history | 16,952 | 8,256 | 8,696 | 3,819 | 2,184 | 1,635 |
| Theology and religious vocations | 5,815 | 3,469 | 2,346 | 1,422 | 1,101 | 321 |
| Transportation and materials moving | 802 | 679 | 123 | 0 | 0 | 0 |
| Visual and performing arts | 13,183 | 5,646 | 7,537 | 1,278 | 594 | 684 |

SOURCE: U.S. Department of Education, National Center for Education Statistics, 2004-05 Integrated Postsecondary Education Data System (IPEDS), Fall 2005. (See Digest of Education Statistics, 2006, Table 258, http://nces.ed.gov/ipeds/data/ipeds_data_query_tool.asp, accessed October 22, 2007.)

TABLE H-2 Selected Graduate Education Characteristics, by Science and Engineering Field

| Field | Graduate Enrollment in 2005 | 30-Year Growth Trend | 5-Year Growth Trend ^a | Ratio of Awarded | | Employment Destination for Ph.D.s ^c |
|-------------------|-----------------------------|----------------------|----------------------------------|---|---------------------|--|
| | | | | Master's Degrees to Ph.D.s ^b | Ph.D.s ^b | |
| Engineering | 120,473 | High | Flux | 5.9 | 5.9 | Industry |
| Health | 104,444 | High | High | 21.7 | 21.7 | Academia |
| Social sciences | 99,846 | Flux | Moderate | 6.7 | 6.7 | Academia |
| Life sciences | 81,572 | Moderate | Moderate | 1.7 | 1.7 | Academia |
| Ag. sciences | 13,123 | Moderate | Moderate | 4.0 | 4.0 | (industry is catching up to academia as a destination) |
| Bio. sciences | 68,449 | Moderate | Moderate | 1.3 | 1.3 | Academia |
| Psychology | 57,412 | Moderate | Moderate | 4.6 | 4.6 | Academia |
| Physical sciences | 51,223 | Flat | Moderate | 1.2 | 1.2 | Industry |
| E/A/O | 14,827 | Flat | Moderate | 2.3 | 2.3 | |
| Physics | 13,472 | | Moderate | 1.4 | 1.4 | |
| Chemistry | 21,122 | | Moderate | 1.0 | 1.0 | |
| Computer science | 48,046 | High | Negative | 20.9 | 20.9 | Industry |
| Mathematics | 20,210 | Flat | High | 4.0 | 4.0 | Academia |

^a5-year growth trend definitions:

Negative—smaller enrollment in 2005 than in 2001; at least three years of decreases.

Flux—no clear trend; two years of increases and two years of decreases.

Moderate—larger enrollment in 2005 than in 2001; at least three years of increases.

High—enrollment increase of at least 20% from 2005 to 2001; at least three years of increases.

^bRatios hand-calculated based on 2004 data from NSF/SRS *Science and Engineering Degrees: 1966–2004*.

^cEmployment destination based on largest number of S&E doctorate holders reporting employment in one of three fields for 2003: education (academia); industry/self-employed; and government.

SOURCE: National Science Foundation/Science Resources Statistics: (1) Graduate enrollment data and trends from NSF/SRS, Survey of Graduate Students and Postdoctorates in Science and Engineering, (2) Ratio of master's to doctorate degrees calculated from data in Table F-2, (3) employment destination for Ph.D.s from NSF/SRS, Survey of Doctorate Recipients.

TABLE H-3 Bachelor's, Master's, and Doctorate Degrees Awarded, by Science and Engineering Field, 2004

| Field | Bachelor's Degrees Awarded in 2004 | Master's Degrees Awarded in 2004 | Doctorate Degrees Awarded in 2004 |
|-------------------|------------------------------------|----------------------------------|-----------------------------------|
| Engineering | 64,675 | 33,872 | 5,776 |
| Health | 68,511 | 37,511 | 1,730 |
| Social sciences | 137,557 | 27,682 | 4,131 |
| Life sciences | 80,933 | 11,777 | 6,983 |
| Ag. sciences | 17,041 | 4,221 | 1,046 |
| Bio. sciences | 63,892 | 7,556 | 5,937 |
| Psychology | 82,510 | 15,298 | 3,336 |
| Physical sciences | 18,143 | 5,600 | 4,025 |
| E/A/O | 3,903 | 1,570 | 672 |
| Physics | 4,156 | 1,637 | 1,186 |
| Chemistry | 9,305 | 2,056 | 1,987 |
| Computer science | 57,405 | 19,853 | 949 |
| Mathematics | 13,755 | 4,297 | 1,075 |

SOURCE: National Science Foundation, Division of Science Resources Statistics. 2006. *Science and Engineering Degrees: 1966–2004*. Arlington, VA: January 2007.

Appendix I

Recommendations for Master's Education in Reports of Leading Science, Innovation, and Higher Education Organizations

Federal support for research and graduate and postdoctoral education should respond to the real economic needs of students and promote a wider range of educational options responsive to national skill needs. Federal strategies should:

- Ensure that federal stipends for graduate and postdoctoral students provide benefits and are competitive with opportunities in other venues;
- Invest in innovative approaches to doctoral and master's education that prepare students for a broad range of disciplinary and cross-disciplinary careers in academia, government, and industry; and
- Provide consistent, long-term support for high-quality disciplinary and interdisciplinary doctoral training programs in S&E.

—National Science Board, *Science and Engineering Workforce: Realizing America's Potential*, NSB-0369 (2003) <http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf>.

The *Professional Science Master's Degree* concept provides an alternative for students interested in STEM areas but not interested in the lengthy time it takes to obtain a Ph.D. The concept was launched in 1997 through the help of the Sloan Foundation and the Council on Competitiveness. Today, this type of degree is available at 45 universities. The Administration should strongly advocate these programs.

—President’s Council of Advisors on Science and Technology, Workforce/Education Subcommittee, *Sustaining the Nation’s Innovation Ecosystem: Report on Maintaining the Strength of Our Science and Engineering Capabilities* (June 2004) <http://www.ostp.gov/PCAST/FINALP-CASTSECAPABILITIESPACKAGE.pdf>.

TALENT: Build a National Innovation Education Strategy for a diverse, innovative and technologically trained workforce:

- Establish tax-deductible private-sector “invest in the future” scholarships for American S&E undergraduates
- Empower young American innovators by creating 5,000 new portable graduate fellowships funded by federal R&D agencies
- Expand university-based Professional Science Master’s and traineeships to all state university systems
- Reform Immigration to attract the best and the brightest S&E students from around the world and provide work permits to foreign S&E graduates of U.S. institutions

—Council on Competitiveness, *Innovate America: Thriving in a World of Challenge and Change*, National Innovation Initiative Report (December 2004) <http://www.innovateamerica.org/webscr/report.asp>.

Increase the retention rate of undergraduates in science, technology, engineering and math majors by expanding programs such as NSF’s Science, Technology, Engineering and Mathematics Talent Expansion Program (STEP Tech Talent), and by offering programs such as the Professional Science Masters that encourage college graduates to pursue fields outside of academia that combine science and/or math with industry needs. Encourage private sector involvement in consortia of industries and universities that establish clear metrics to increase the number of graduates. (*Higher Education, Business, Federal, State*)

—U.S. Chamber of Commerce, *Tapping America’s Potential: The Education for Innovation Initiative* (2005) http://www.uschamber.com/publications/reports/050727_tap.htm.

Continue to establish and build on professional science masters programs that meet specific science and technical managerial workforce needs identified by the federal government, business, and industry.

—Association of American Universities, National Defense Educa-

tion and Innovation Initiative: Meeting America's Economic and Security Challenges in the 21st Century (January 2006) <http://www.aau.edu/reports/NDEII.pdf>.

The professional master's degree is a promising new initiative that is shaping graduate education in direct response to changing workforce needs in the business, nonprofit, and government sectors. . . . In the STEM fields, the PSM combines advanced study with professional and interdisciplinary training. The two-year PSM degree includes four basic components: advanced science or mathematics courses which comprise approximately two-thirds of requirements; "plus" courses in business principles and other professional skills, such as written and oral communication, intellectual property, and entrepreneurship; a summer internship in a targeted employment sector; and a capstone project often done as part of an interdisciplinary team. PSM programs are specifically designed to meet the needs of local, nonacademic employers with input from advisory boards representing the employment sector. . . . The combination of advanced science or math, interdisciplinary exposure, and professional business skills creates highly adaptable graduates interested in innovation. As such, the PSM can serve as a model for professional stand-alone master's degrees in a wide range of fields. . . . Recommendation: Continue to expand innovative professional master's degrees in order to address pressing national needs in such critical fields as mathematics, science, engineering, social sciences, and humanities.

—Council of Graduate Schools, *Graduate Education: The Backbone of American Competitiveness and Innovation* (April 2007) http://www.cgsnet.org/portals/0/pdf/GR_GradEdAmComp_0407.pdf.

Professional Science Masters (PSM) programs are useful tools for helping states meet the increasing need for well-trained problem solvers in technology-based industries. PSM is an innovative new graduate degree developed to provide advanced training in science or mathematics while simultaneously developing workplace skills highly valued by employers. Many postsecondary institutions and, increasingly, states are adopting PSM as a tool to meet workforce needs. In 2006, the California State University (CSU) became the first statewide higher education system in the nation to make PSM degrees available on multiple campuses. CSU's PSM-degree programs have been developed in concert with the growth industries in biotechnology, medical, and computational sciences.

—National Governor's Association, *Innovation America: A Compact for Postsecondary Education* (July 2007) <http://www.nga.org/Files/pdf/0707INNOVATIONPOSTSEC.PDF>.

PROGRAMS AUTHORIZED—The Director [of the National Science Foundation] shall award grants to 4-year institutions of higher education to facilitate the institutions' creation or improvement of professional science master's degree programs that may include linkages between institutions of higher education and industries that employ science-trained personnel, with an emphasis on practical training and preparation for the workforce in high-need fields.

—U.S. Congress, *America COMPETES Act* (H.R. 2272), passed by the U.S. Congress and signed by the President of the United States (Summer 2007) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h2272enr.txt.pdf.

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- Carnegie Initiative on the Doctorate. <http://www.carnegiefoundation.org/programs/index.asp?key=29>.
- Council of Graduate Schools, Professional Master's Initiatives. <http://www.cgsnet.org/Default.aspx?tabid=120>
- Keck Graduate Institute of Applied Life Sciences. <http://www.kgi.edu/>
- National Research Council, Enhancing the Master's Degree in the Natural Sciences (includes links to presentations to the study committee that authored this report). <http://www7.nationalacademies.org/bhewmasters/>
- Professional Master's Degree Programs in the Mathematical Sciences. <http://www.ams.org/tools/masters.html>
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NOTE: All URLs accessed on January 29, 2008.

