Mastering Science:

Graduate Schools Invigorate the MS in Science and Math

Jesse H. Ausubel and Sheila Tobias

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About the Authors

Jesse H. Ausubel is a program director with the Alfred P. Sloan Foundation (http://www.sloan.org). He is part of the team that created "Virtual U", a university simulator in which the player is the president and the game is to survive. Sheila Tobias wrote *Overcoming Math Anxiety* (1978) and co-authored *Rethinking Science as a Career* (1995). She has received eight honorary doctorates for her contributions to improving science and math education and career opportunities for women.

Jesse H. Ausubel, Alfred P. Sloan Foundation, 630 5th Avenue, New York NY 10111-0242; phone 212-649-1650; fax 212-757-5117; email: ausubel@sloan.org

Sheila Tobias, 724 North Campbell Avenue, Tucson, AZ 85719; phone: 520-628-1105; fax: 520-882-6973; email: sheila@sheilatobias.com

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During the past five years, a movement to professionalize the master's degree in the sciences and mathematics has taken hold. Some 40 universities have established new degree programs in response to a growing recognition that a master's degree that is merely a graceful exit from the long road to a Ph.D. does not capture the breadth or variety of exciting and lucrative careers in an economy that rests increasingly on science and mathematics. Cross-disciplinary fields, components of business and law, and collaboration of business and university distinguish the professional science master's (PSM). Employment has proven the worth of a PSM to students. And parallel growth of both PSMs and Ph.D.s has proven their worth to universities.

Although fully a decade ago, Clifton Conrad, Judith Glazer, and others described master's level education as the fastest growing sector of higher education, its "silent success" largely passed science and mathematics by. Business administration, journalism, architecture, engineering and a range of other professions already looked to universities to provide the post-baccalaureate educational experience that is the foundation of rewarding professional careers. But fewer than three percent of master's degrees awarded were in the sciences and mathematics. Between 1984 and 2000, according to the National Center for Education Statistics, professional master's degrees awarded in U.S. universities climbed from 271,000 to 366,000, and doctorates in math, physical, and life sciences rose from about 7,500 to 10,000. In contrast, the number of master's degrees awarded in these fields stayed flat at about 14,000.

That the sciences and mathematics joined late in the professional master's degree movement is understandable. But the past few years have seen a change: the establishment of master's degrees at doctoral institutions in such specialties or cross-disciplines as bioinformatics, industrial mathematics, and computational linguistics. In this article, we review the reasons for the initial hesitation in the sciences and mathematics; some recent history; features of the new degrees; current status; and the challenges ahead.

A Late Start

Historically, graduate education has been targeted on a narrowly specialized academic research career. Research funding has, therefore, largely determined the size and structure of graduate programs as Malthus theorized food would set humanity's population. The model driven by research grants heavily encourages large populations of pre- and post-doctoral students apprenticing many years. Faculty preferences have determined the teaching mode: research seminars rather than courses teaching more structured bodies of knowledge. Thus, the course-intensive training with internship or practicum that characterizes the master's in business and other professions has had no counterpart in the sciences and mathematics.

Before university scientists and mathematicians could embrace the professional master's degree concept, they had to be persuaded first, that the education could provide an alternate, no less rigorous set of competencies that would qualify students for careers not at the bench; second, that employers would recognize and value the credential; and third, that the benefits to faculty and their departments would exceed the costs.

In fact, Jay Walton, whose mathematics department at Texas A&M began offering the professional master's in applied mathematics in 1994, attributes the following positive effects to the new degree:

> Increased visibility for the department both inside and outside the university, an increase in collaborations with other departments, an increase in graduate mathematics course enrollments by non-mathematics graduate students and an increase in the proportion of university resources targeted for the mathematics graduate program.

According to Walton, none of these benefits has come at the expense of the Ph.D. program in mathematics at Texas A&M. That program has steadily increased in size and quality over the same eight years.

Other PSM program directors see value in their new contacts with local and regional firms, which expose the students and faculty to real-world problems and state-of-the-art instrumentation. Faculty note the stimulus of teaching motivated graduate-level students with diverse orientations. Departments benefit from more students. Because 84% of those currently enrolled in PSM programs are U.S. nationals, departments also gain native English-speakers for assignments as teaching assistants. Eventually, as their own undergraduates see a wider variety of post-baccalaureate options in science and mathematics, undergraduate courses in science and math may attract more numerous and interesting students.

Some feared at the beginning that PSM programs might compete with the local Ph.D. programs for students, faculty time, and resources. Sometimes they do, but so far few Ph.D. students are shifting into master's programs (or the reverse). On the contrary, benefits spill over for doctoral students. For example, intensive short courses in computer science developed for the professional master's students usually are open, as are the new courses in "business basics," intellectual property law, and regulatory affairs. And even the new disciplinary and interdisciplinary science courses attract Ph.D. students. The University of Southern California's two new offerings, computational physics and complex systems, developed for its Physics for Business Applications Master's program regularly enroll Ph.D. students. And many graduate students may benefit when a graduate department broadens contacts and actively supports job placement beyond the academic archipelago.

Recent History

The PSM movement began in the late 1980s, when about a dozen universities established new master's programs professional in nature if not in name, largely in financial mathematics and biotechnology. At such institutions as Northwestern, Carnegie Mellon, University of Chicago, New York University, State University of New York at Stony Brook, and Columbia, these programs stood alone, that is, they did not propagate to other fields, either within their own institutions or outside. Also, with the exception of the Society for Industrial and Applied Mathematics (SIAM), which worked throughout this period to expand the concept of a PSM in applied and industrial mathematics, the disciplinary associations did not take much notice until after 1997. But Deans and Provosts did.

In 1997, encouraged by the growing need, the William M. Keck and Alfred P. Sloan Foundations, independently, began to help launch new PSM degrees. Henry Riggs, the outgoing president of Harvey Mudd, the science and engineering college in the Claremont Colleges group, approached Keck. Riggs wanted to build an all-new master's-only graduate school to supply California's biotech industry with professionals expert in the life sciences, mathematics, and engineering, but also savvy about intellectual property rights, finance, and business management. The resulting Keck Graduate Institute (www.kgi.edu), associated with the Claremont Colleges in California, enrolled its first class of twenty-eight students in August 2000 and is growing to 60 per class in 2002.

Sloan was willing to entertain programs of study rooted in science or math departments for which a faculty group could show strong, lucrative job possibilities for graduates at the master's level. In the summer of 1997, the first grant for programs was awarded to the College of Science at Georgia Tech in bioinformatics, human-computer interaction, and financial mathematics. Sloan followed with grants to an additional thirteen universities, and a targeted bioinformatics set of programs at another twelve. (On the Web at www.sciencemasters.com.) Sloan expected its grantees to try a variety of subject areas but within certain guidelines: analysis of local and regional workforce needs had to precede development of program content; an active involvement from the outset of industry/business advisers; and programs of two years' duration including three- to six-month internships.

Several grounds justify two years rather than one beyond the big volume of material to master. Faculty don't take seriously students who come and go in one year. Second-year students are important mentors to first-year students and, when they graduate, provide personal links to the job market. And, finally, two-year programs generate a greater sense of community and because of this more loyalty to the institution, among their graduates.

Features of the New Degree

The breadth of the PSMs, and its radical departure from doctoral education in the sciences and mathematics, recalls the founding in 1908 of another new two-year degree, the MBA. Its founders intended the MBA not just to comprise a new subject, "management science," but to distinguish itself by way of a new pedagogy, "the case method," a philosophy that "…business is an activity of both economic and social consequences," and a commitment to make the MBA a professional degree of the highest quality. In the same manner, even in a few short years, certain features of the professional science master's have become distinctive.

One feature is curriculum content. Science master's programs offer more technical content than the MBA, more business than the science Ph.D, and often more information technology than both. Many programs are in emerging fields, such as bioinformatics, or cross-disciplinary fields such as human-computer interaction. Others offer a broader or more applications-driven sequence, as the industrial mathematics master's at Michigan State University, where cases are routinely solicited from industry for students to solve in teams, or financial mathematics at Worcester Poly and Georgia

Tech. Then, there are environmental programs, combining environmental science with other analytic skills, as University of Southern California's environmental risk management, South Carolina's environment and geosciences, and Rice University's environmental analysis and decision- making.

Most programs include an explicit "professional" component, sometimes a set of courses for the entire cohort of PSM students in all MS degree tracks in business basics, law, or regulatory affairs, together with skills-building modules, if not whole courses, in management, negotiation, and communication. At Michigan State University, the institution has established a ten-weekend intensive certificate program of business skills, required of master's students in all of MSU's seven science/math programs (now open to graduate students in other science fields as well). At the University of South Carolina, the project management course incorporates tech-business cases gathered from local business and akin to the case studies of business schools. Physics PSM students at Southern California join regular business students for two courses in the Marshall School of Business. These out-of-specialty courses, whether cross-listed or tailor-made, teach interdisciplinary team building and help construct the unique and shared identity of the PSM. Institutions incorporate other distinctive PSM experiences into orientation, special colloquia, placement services, and social events.

Several of the new degree programs involve specific applications of computer science across disciplines, such as computational chemistry (Michigan State), bioinformatics (12 universities), geographical information systems (Pittsburgh and Wisconsin), and computational linguistics (Univ. of Southern California). But even those that do not emphasize computer science provide their master's students with more exposure to the tools of information technology than do most other graduate programs. Especially relevant to the sciences are data-base management, data-mining, and simulation.

A key asset in these new PSM degrees are the business/industry advisory committees set up before launching the program. These open a consumer's view to faculty on course content and sets of skills plus the design of internships. They enhance credibility within the business community. Not least, they open networks that will hire graduates. Program directors find that feedback loops to and from employers are essential to keep a program successfully tuned to their labor markets.

One reason that program directors from several different universities are now cooperating – apart from the encouragement of their funders – is their clearly articulated sense that "we're all in this together." However varied their individual programs, the universities know that the PSM will largely rise or fall on the quality and viability of their *collective product* – the kind of students they attract and the kinds of jobs they get. Sloan contributes technical assistance in the form of inter-program travel, meetings, list serves, and recruitment support. A shared web site publicizes programs funded by Sloan and others as well. For the PSM movement to gain national momentum, many institutions must pull together. In fact, no science or math department is large enough to meet a big share of the likely national market. Probably 100-200 schools can thrive in it.

Issues and Challenges

A big issue for the professional master's degree program is "Who pays?" Students pay (and borrow) for an MBA, a law degree, or a master's in public health. In contrast, students in the sciences and mathematics pay only little toward the cost of a Ph.D. Research funding, training grants, and fellowships subsidize them and their mentors. If students can be persuaded that the PSM will open a profession as an MBA or law degree will, they will invest their time and money in a two-year program. But until a large number of PSM students graduate and get good jobs, programs are priming the pump by teaching assistantships or other university support. Many report that their students are sufficiently entrepreneurial to find work on a large campus on their own (particularly if they have computer skills). So, in the case of computational linguistics at USC, there has been no financial support. In contrast, the Keck Graduate Institute, which intended to subsidize only its first class, ended up subsidizing the second as well.

Tuition and fees are but two dimensions of the economics of the PSM. Experience suggests that the full cost including overheads for starting up a single new degree program ranges between $75,000 and $300,000, depending, for example, on number of new courses, equipment purchased, and personnel hired. Because these programs require less faculty than traditional doctoral science education, many use their startup funds to hire professional staff for faculty coordination, targeted recruiting, student services (including advising), and as liaisons to business/industry. Another option is to provide summer salary to program faculty willing to take on the management tasks as part of their normal assignment.

Because programs are housed in academic departments and managed within the normal College of Science structures, they mostly conform to local tuition and rules of revenue return. But as programs try to become financially self-sufficient, this may change. At San Jose State University, the new PSM in biotechnology may eventually carry a higher tuition than other master's degrees (closer to that of the MBA at that institution), a portion of which will be returned to the program for expansion of biotechnology or for additional PSMs. The co-program directors at the University of Connecticut are negotiating a comparable arrangement for their microbial systems analysis and financial mathematics PSM. But so far these are the exceptions. Long-term financial support is hoped for, eventually, from business, industry, and even government, as they see benefits from programs' graduates. Because many master's graduates remain in the state where they train (unlike Ph.D.s, who seek work in a national market), state economic development agencies should find PSM programs worthy of support as workforce incubators.

Size matters for these master's programs. It is hard to establish a program's clear and distinct identity, create project teams, and cultivate camaraderie with a mere handful of students. In two to three years, when these programs are up and running, they aim for *at least* ten graduates per degree program per year. Each program needs to achieve a high profile to build strong ties to industry and business and to recruit able students. Program directors also want their master's students to have a defined and dynamic experience, different from the leisurely pace of doctoral education. To this end, institutions are conducting distinctive orientations for their professional master's students, and providing cross-departmental activities. They provide special advising and placement, and track their graduates over the long term.

Quality control also matters. So far, quality measures are entirely in the hands of local faculty and institutions. But as the number of institutions grows without the boards, bar exams, certification or accreditation that set standards in the older professions, national ways to assure professional standards may arise. In the U.S., the bachelor's degree is defined by the number of credits earned and the Ph.D. by the dissertation and the mentor's reputation. The master's degree, in contrast, is the least standardized in terms of time and work requirements. Whether consortia of institutions involved in the various stripes of professional science master's will determine what constitutes a sound program and accredit them remains to be seen. Perhaps the National Research Council and National Academy of Sciences, often influential in setting standards for math and science education, can help establish norms for the PSM.

An important group, often well-connected with their local industrial and business communities, already award 40 percent of the science and mathematics master's degrees. They are institutions focused on master's rather than doctoral degrees. In general, however, these degree programs are not professional – as we are using the term – either in their structure or their students' orientation. Transforming some of these programs will bring its own set of challenges. Starting in 2002, the Council of Graduate Schools (CGS) is encouraging just such institutions to determine whether it is to their benefit to professionalize one or more of their science master's degrees or to develop altogether new degree programs. CGS estimates that some 2,000 new PSM graduates could come from master's focused institutions, once programs have been transformed as into PSM.

National Impact

Producing a few hundred science- or mathematics-trained professionals is good for individual careers, but to affect the national economy, the U.S. will have to graduate thousands. We believe these graduates will have value to the nation in several ways.

Above all, they will share with engineers the tasks of keeping the nation a leader in a wide range of cutting-edge industries and suffusing math and science into industries that needed little before. They will also bring to more workplaces a high level of science literacy and capacity to interface between researchers, other specialists, and the general public. So a critical challenge is how to grow these programs?

The U.S. now graduates about 100,000 bachelors' degrees in the sciences and mathematics annually, 3,500 in physics, 3,000 in geology, 11,000 in chemistry, 12,000 in mathematics, and by far the largest portion, 67,000 in the biological sciences. Reportedly, one-third do *not* go on to any graduate or professional school within five years of graduating from college. This fact alone suggests a fresh potential pool yearly of at least 30,000 for the professional master's. And, as the degree becomes more prestigious, that pool and the total numbers of majors from which it derives may increase as well. Expansion depends of course not just on the pool but on some means of reducing costs to students either by public- or private-sector subsidies; more favorable distribution of state allocations to master's degree programs; and simply an increase in the number and variety of programs in both doctoral and master's focused institutions.

Whether universities award hundreds or thousands of science master's degrees each year within the decade, however, will depend at least as much on leadership outside universities as within. Federal government agencies, including NSF, NIH, DOE, NASA, and DOE power graduate science and mathematics education. The government agencies have strongly encouraged production of doctorates, but their policies and practices have largely ignored master's level education. These agencies should think carefully how PSM degrees match their missions.

Indicators of success converge. Applicant pools and job placements strengthen. Faculties grow eager to teach and develop new programs. Business and government interest and support rises. Administrators see the new degrees as ways to raise institutional visibility and reputation by connecting to regional economic development. Faculty see PSMs opening doors and strengthening departments. Over the next few years, actions by all the stakeholders can make this young movement an essential component of U.S. higher education. Examples of PSM and Ph.D. programs growing in parallel rather than in zero-sum draw all ahead.

Suggested Sidebars

Sidebar 1 For listings of PSM programs by school, discipline, and region, on-line articles, news of upcoming meetings, and other information visit www.sciencemasters.com

Sidebar 2 Likely applicants

- People who want technical careers in industries not normally seen as science-based, such as finance or film.
- Seniors and recent science/math graduates who want to go into management rather than research and teaching.
- Graduates in science or mathematics one to five years out who are looking for career advancement.
- Mid-career professionals who would like to cross over to a new technical field.
- Women and minority students who are ambitious but for whom the Ph.D. degree does not offer the requisite flexibility or rapid entry into the workforce they desire.

Sidebar 3 Keck Graduate Institute orientation experience. All entering students to KGI participate in a three-week case-study project. The project orients new students to the biosciences industry, familiarizes them with team-conducted project work and project management, and encourages cross-disciplinary thinking and creativity. Orientations such as Keck's contrast strongly with the solitary and often rather haphazard beginning of doctoral education in the sciences.

Sidebar 4 Good Practices Check List for Launching PSM Programs

Planning

- Begin only with a committed, entrepreneurial program leader
- Learn about jobs and labor markets for graduates, including salaries, especially by visiting sites of possible employment
- Form advisory board of industry and other likely employers
- Define scholarly rationale for the proposed degree program and its content
- Assure faculty enthusiasm for the new degree, including commitment by regular department faculty to provide bulk of instruction
- Win high-level institutional commitment to master’s level education, including central coordination of all PSM programs at level of dean or above
- Prepare business plan projecting both expenses and revenues, and showing how and when each degree program can become self-sustaining based on tuition revenues, corporate support, university support.
- Set targets for applications and enrollments

Curriculum

- Offer intense identity-building or “branding” experience for PSM’s, including team project for entering students
- Develop "signature" courses in the disciplinary or interdisciplinary substance of the program

- Develop the "professional" component of the program, alert to opportunities for certification and other forms of credentialing
- Require business/industry internships
- Include exposure to cutting-edge research issues and equipment, for example, by lab rotations
- Conduct seminars/colloquia jointly for all PSM students
- Teach writing/communication/negotiation/consensus-building and other workplace assets
- Require final project, often team experience, in which meeting a schedule really matters (in contrast to the open-ended nature of much university research)

Program Management

- Create management teams dedicated to recruitment of students and placement of graduates
- Appoint personnel to handle student retention and services; liaison to business and industry; publicity; intra-university coordination (e.g., with Business School)
- Win rapid approval of new degree programs by state Regents and other gatekeepers
- Set up systems to keep track of graduates and network them
- Keep contact with other professional master's programs around the country
- Set up systems for assessment and quality control

Related Readings

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