Professional Science Master's Programs in the Mathematical Sciences

Bogdan Vernescu, Worcester Polytechnic Institute
Joaquin Carbonara, Buffalo State (SUNY)
Paul Eloe, University of Dayton
Aric LaBarr, North Carolina State University
Diana Thomas, Montclair State University

What is a PSM?

At the end of the 1990s a new graduate degree came to life, as a response to strong workforce demands for STEM professionals. The two-year program leading to the Professional Science Master's (PSM) degree was conceived to supplement strong interdisciplinary knowledge in science and mathematics, with expertise in business areas such as communications and project management. The PSM degree is appropriate for those who aspire to careers in business, industry, or government within mathematical or scientific contexts. Typically, entry to such jobs requires expertise beyond that offered by a bachelor's degree. That PSM programs meet a need in US higher education is confirmed by the rapid expansion of these programs: over 300 now exist in a variety of disciplines.

PSM programs range from biotechnology and pharmaceuticals to nanotechnology and agriculture. All are based on the need of scientific, business, or government enterprises for employees with solid scientific and technical backgrounds that complement business skills and interests. The first mathematically-oriented PSM programs originated in Financial and Applied Mathematics (or in similar programs called Industrial Mathematics or Computational Mathematics), followed recently by Bioinformatics and Data Analytics programs, which have significant mathematics and statistics components. The National Professional Science Master's Association coordinates and highlights activities of the various institutions offering PSM programs. These interdisciplinary programs are usually designed in cooperation with business,industry, and government to reflect their needs in specific technical areas. In general, PSM degree programs combine higher-level scientific and technical coursework with courses in business.

What do PSM programs seek to accomplish?

PSM programs vary widely in structure and areas of emphasis, but they share some general features and purposes.

Cognitive outcomes. Mathematics-focused PSM programs, regardless of area, promote several key attitudes, practices, and abilities.

- **Analytical thinking**: Students' strong theoretical mathematics and/or statistics knowledge supports deep understanding of important applied problems.
- **Modeling skills:** Students are comfortable using mathematics and statistics to model real-world problems.

- **Professional and leadership skills:** Students acquire expertise in mathematics and statistics; professional and leadership skills in communication, management, and team building; and the flexibility to adapt to corporate needs.
- **Collaborative skills:** Students learn to collaborate through team projects and internships.

Content outcomes. Content requirements differ among mathematics-rich PSM programs, but all programs apply mathematical and statistical knowledge, reasoning, and techniques to problems in their fields. Facility in these areas is developed through components common to all PSM programs:

- mathematics and statistics core courses;
- management and business courses;
- real-world projects and internships.

Mathematical content is used in different ways in different PSM programs. The following example suggest some of this variety.

> **Industrial/applied and computational mathematics:** Students learn to apply mathematical and computational tools to model problems from various science and engineering fields. Students learn to distill the underlying mathematical model from the stated problem, develop qualitative analysis of the solution, determine the acceptable approximation, and understand the importance of the data and accuracy needed. Students learn to find, interpret, and convey results in the language and context of the original problem, respecting real-world constraints that may dictate approximate, probabilistic, or numerical solutions.

> **Financial mathematics:** Graduates use mathematical and computational tools to model pricing of financial derivatives, fixed income securities and their derivatives, portfolio valuation, credit markets, and risk management. Students learn about business and economics through courses regularly included in MBA programs. They also encounter computer programming, algorithms, database design and management, and the design of software systems.

> **Data analytics:** Graduates must use mathematical, statistical, and computational tools effectively to analyze large data sets and apply results to fact-based decision-making. Graduates must translate a business problem into a data problem that can be solved, with results that inform a business solution. These steps involve the understanding both of business and of techniques for data mining, data visualization, machine learning, and distributed computing.

> **Bioinformatics, biotechnology, and genomics:** Graduates must use sophisticated statistical tools along with mathematical and computational analysis to manage and interpret biological data. Students must learn to analyze and model complex biological phenomena, combining strong statistical reasoning and computational skills with understanding of biomedical aspects of the problem.

Recommended undergraduate preparation for mathematics-focused PSM programs

While there are many PSM programs in mathematics and related fields, each with its own admission requirements, there is a commonality of background and experience that can prepare a mathematics major for successful admission to and graduation from a PSM program. Some institutions offer a so-called BS/MS (4+1 years) program: high performing undergraduates who have completed the prerequisites for the PSM can take graduate courses while enrolled as undergraduates, and thus complete both undergraduate and PSM degrees in 5 years.

This background and experience can be obtained from course work and involvement in professional activities. Some undergraduate programs offer credit for experience working in the field. Some PSM programs (e.g., in Data Analytics or Bioinformatics) admit students who do not have a mathematics undergraduate degree. Because admissions criteria depend on program site, here we describe universal criteria only for mathematics majors; readers should consult specific institutional websites for other cases. NPSMA lists institutions and departments offering the degree, along with information on specific programs and their admission requirements.

Mathematics courses. All PSM programs require calculus (including multivariate), linear algebra, and probability and statistics. Some computing experience or familiarity with software packages is also expected. Experience with mathematical modeling is highly desirable. This may involve coursework in modeling, mathematics-intensive courses in other sciences business or economics, or out-of-class experience in an applied field. Requirements for additional courses vary with area of the PSM:

- **Industrial/applied and computational mathematics**: Differential Equations, Discrete Mathematics, and Numerical Methods. Courses in engineering or sciences, depending on the area of interest, including programing/computing courses.
- **Financial mathematics**: Differential Equations, Real Analysis, Discrete Mathematics, Numerical Methods. Courses in business (e.g., accounting), economics, or finance. Experience with basic computer programming (MATLAB, R, Java, C++, Python).
- **Data analytics**: At least two courses in statistical methodology/regression, experience with statistical/mathematical computing (SAS, SPSS, R, Minitab, Python, etc.).
- **Bioinformatics**: At least two courses in statistical methodology/regression, Numerical Methods, experience with statistical/mathematical computing (SAS, SPSS, R, Minitab, Python, etc.). Additional courses in biology (e.g., cell biology, genetics, and molecular biology), organic chemistry, and programming/computing.

Other experience. It is important for prospective PSM students to have completed courses in other science, engineering, and business disciplines. Alternatively, some students might acquire perspective on other disciplines through extracurricular experiences such as summer work, internships, or research opportunities. Such experiences both help students make informed career choices and contribute to their success in PSM programs. Previous experience with applications of mathematics and statistics to other fields and with problem solving in a real-world settings is also valuable.

Collaboration is crucial to training for careers in business, industry, or government; experience with teamwork on any project is an asset to PSM program applicants. Teamwork with people from diverse backgrounds helps students see things from different perspectives. Collaborative experiences can be arranged through undergraduate class projects, internships, or research projects with other students and faculty.

Clear communication in oral and written forms is essential; students should develop these skills as undergraduates both through writing courses and by preparing written class and project reports. Students can build oral presentation skills through mathematical presentations---especially to non-mathematical audiences. PSM programs develop these skills further by requiring at least one major team project; teams must present results to both technical and non-technical audiences.

Faculty advisors should inform themselves and their undergraduate students about master's programs that support careers requiring significant mathematical and statistical knowledge and skills. Online NPSMA resources can assist faculty and their advisees in understanding the relatively new PSM degree. This *Guide* offers general advice about undergraduate preparation for PSM programs, but faculty should advise students to research particular PSM programs as early as possible. Doing so will permit students to choose courses best suited to prepare them for admission to PSM programs of their choice. See also [1], the proceedings of an NSF-sponsored workshop on PSM programs in mathematical sciences, for more information on existing programs, curriculum, industrial experience, placement of graduates and future trends.

References

1. J. Carbonara and B. Vernescu (eds), *Creating Tomorrow's Mathematics Professionals*, COMAP, 2013.