The INGenIOuS Project

Mathematics, Statistics, and Preparing the 21st Century Workforce

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MATHEMATICAL ASSOCIATION OF AMERICA

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About the project

The INGenIOuS Project is a joint effort, focused on workforce development, of the Mathematical Association of America and the American Statistical Association, in partnership with the American Mathematical Society and the Society for Industrial and Applied Mathematics, with funding from the National Science Foundation through grant DMS-1338413.

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Appendices

The appendices listed below can be found online in the complete report:
http://ingeniousmathstat.org/pdfs/INGenIOuS-report.pdf

I. Executive summary

The need for more students to enter the workforce well equipped with mathematics and statistics skills has been acknowledged in many recent reports. Addressing this need will require action by all stakeholders involved or interested in students' preparation for present and future workforce demands.

The INGenIOuS[1] project, a collaboration among mathematics and statistics professional societies and the National Science Foundation, culminated in a July 2013 workshop devoted to identifying and envisioning programs and strategies for increasing the flow of mathematical sciences students into the workforce pipeline. This report describes findings and outcomes of that workshop.

Beginning in summer 2012, representatives of the American Mathematical Society (AMS), American Statistical Association (ASA), Mathematical Association of America (MAA), and Society for Industrial and Applied Mathematicians (SIAM) populated a committee to advise the NSF on key workforce development issues. This group oversaw the formation of "communities" focused on six themes:

Theme 1: Recruitment and retention of students

Theme 2: Technology and MOOCs

Theme 3: Internships

Theme 4: Job placement

Theme 5: Measurement and evaluation

Theme 6: Documentation and dissemination.

Each community leader hosted an online panel on one of the themes and then summarized pertinent issues and discussion in a white paper. These six white papers (Appendix B) provided essential background information for workshop participants, but the July 2013 workshop itself focused specifically on concrete programs and strategies, new or existing, for moving ahead.

Appendix A lists workshop participants and observers, and Appendix C provides additional details on the workshop schedule and agenda. Appendix D includes a wide variety of workforce-related project ideas and initiatives, some new and some already underway, that were articulated at the workshop and then evaluated according to several metrics.

1 INGenIOuS is an acronym for Investing in the Next Generation through Innovative and Outstanding Strategies. Appendix E lists other acronyms and abbreviations used in this report.

The main “products” of the workshop were six main action threads, identified by participants as key areas of effort toward improving workforce development in mathematics and statistics. Action examples and recommendations in each area are discussed in detail in the body of the report; following are brief summaries.

Thread 1: ***Bridge gaps between business, industry, and government (BIG) and academia.*** Ensuring progress toward a well-supplied, sustainable pipeline of professional mathematicians and statisticians will require active collaboration among a broad array of stakeholders. Collaborations might focus on such areas as connecting students to internship opportunities in BIG, facilitating student research experiences with BIG employers, and informing students about the mathematics and statistics needed for careers in BIG.

Thread 2: ***Improve students’ preparation for non-academic careers.*** All students of mathematics and statistics need career-appropriate preparation that emphasizes the centrality of their disciplines to the nation’s broader science, technology, engineering, and mathematics (STEM) enterprise. Better career prospects in mathematics and statistics can boost student recruitment and retention in the short term; in the long term, better preparation will increase the number of graduates who enter the workforce well equipped with skills and expertise in mathematics and statistics. Change is needed both in curricula and in some faculty members’ perceptions of BIG careers for their students.

Thread 3: ***Increase public awareness of the role of mathematics and statistics in both STEM and non-STEM careers.*** Public awareness is scant—even among employers, students, faculty and administrators—about careers with links to STEM disciplines and about the importance of mathematics and statistics for both STEM and non-STEM careers. Public awareness should extend beyond sexy “CSI-type” jobs to a broad range of options, including finance, economics, and medicine, that require strong mathematical and statistical foundations. Progress will require efforts from professional societies, foundations, academic institutions, and BIG entities.

Thread 4: ***Diversify incentives, rewards, and methods of recognition in academia.*** Academic institutions and mathematical sciences departments should maintain high academic performance standards for faculty and students, and also broaden their long-established systems of reward and recognition to include support for 21st century career preparation of students. A well-balanced mathematical sciences program offering a bachelor’s degree or above should include faculty with a variety of interests: discovery research (in pure and applied mathematics and statistics and mathematics education); work in applied, collaborative, and interdisciplinary areas; and teaching and preparation for careers both within and outside of academia.

Thread 5: ***Develop alternative curricular pathways.*** Curricula in the mathematical sciences traditionally aim toward upper-level majors’ courses focused on theory. Shorter shrift is usually given to applications that reflect the complexity of problems typically faced in BIG environments, and to appropriate uses of standard BIG technology tools. The computation that mathematics and statistics majors typically see introduces them to important scientific computing constructs, but it should also help prepare students for big data applications through mathematical and statistical modeling, data analysis, visualization, and high performance computing. Mathematical sciences departments should modernize programs and incorporate alternative curricular entry points to better capitalize on the interplay of mathematics and statistics with a broad spectrum of career options.

Thread 6: ***Build and sustain professional communities.*** Workshop participants repeatedly cited the need to build a national community of professionals involved in workforce development, including stakeholders from academia, BIG employers, professional societies, and funding agencies and foundations. Using the full gamut of virtual and in-person communication tools, such a community would share information and resources, develop best practices, assist faculty in incorporating current technology tools, assess and evaluate programs, identify internships, and improve job placement.

II. Introduction and context

The STEM workforce and the mathematical sciences

By many accounts, the scarcity of science, technology, engineering, and mathematics (STEM) professionals entering the U.S. workforce is a critical challenge facing the mathematical sciences community (National Academy of Sciences, 2009 and 2012; National Research Council, 2013; National Science Board, 2003; President's Council of Advisors on Science and Technology, 2012). This challenge is not new (Cozzens, 2008; National Research Council, 1999; National Science Board, 1986; National Science Foundation, 1996); it is persistent and becoming more difficult to address.

The magnitude and even the existence of a shortage of U.S. STEM workers are sometimes questioned, as for example in *The Chronicle of Higher Education* (Anft, 2013) and on WVTF Public Radio (Hausman, 2013). Indeed, the total annual production of STEM graduates roughly equals the annual number of available STEM positions (Carnevale, Smith, & Melton, 2011).

Yet production of new STEM graduates is only part of the story. For several decades, employment in STEM occupations in the U.S. has grown faster than the job market overall, and this pattern is expected to continue. What may be less apparent is that STEM-related knowledge, skills, and general abilities are increasingly in demand in *non-STEM* occupations. (Classification itself can be non-intuitive. For example, the Bureau of Labor Statistics does not count mathematical scientists working in the education and healthcare sectors as STEM professionals.) In any event, workers' earning potential in jobs that demand STEM competencies is significantly higher than that in jobs without these requirements. While the traditionally classified "STEM occupations" account for only about 5% of the total U.S. job market, occupations that demand or value STEM competencies span the full career spectrum. This broad need for STEM competencies add to the national demand for STEM workers. Data suggest, moreover, that STEM-trained workers divert voluntarily into non-STEM jobs at multiple points along their career paths (Carnevale, Smith, & Melton, 2011).

The reports cited above identify other factors that contribute to a broad and growing national need for STEM-trained workers: greater international competition for professional mathematicians and statisticians; broadening applicability of mathematical and statistical subdisciplines; accelerating retirement of baby boomers; lack of student interest in and awareness of careers in fields that draw on the mathematical sciences; increasing attrition of students, particularly those from underrepresented groups; and outdated curricula and programs.

The “M” in STEM is essential to filling the STEM pipeline. STEM comprises many fields, but mathematics and statistics sit squarely at the core of STEM competencies, including content knowledge, procedural facility, critical thinking, problem-solving ability, and inference from data. Equipping more STEM and non-STEM students with these competencies is key to the nation’s future economic growth, national competitiveness, and national security.
It is important, moreover, not to view STEM as a homogeneous collection of disciplines with identical job prospects and demand. Supply of and demand for biologists, chemists, mathematicians, and statisticians are all different. Even within the “E” of STEM, the demand for aerospace engineers differs from that for manufacturing or petroleum engineers. In any event, workers in all STEM fields need strong grounding in mathematics and statistics.

The INGenIOuS project urges faculty, students, department chairs, administrators, and professionals in business, industry, and government, funding agencies, institutes, and professional societies to work together. The first step is to educate ourselves on STEM workforce-related initiatives. The second—and most important—step is to propose and implement practical strategies and to evaluate and modify them for improvement.

Recent findings and prior recommendations

The mathematical sciences community recognizes significant weaknesses in the pipeline of professional mathematicians and statisticians entering the U.S. workforce. The report *The Mathematical Sciences in 2025* (National Research Council, 2013), for example, recommends that the training of future mathematical and statistical scientists be reassessed in light of the increasing breadth and cross-disciplinarity of mathematical and statistical fields. Although some promising strategies have been identified, few such practices have been implemented widely enough to have broad impact. Plugging leaks in the workforce pipeline, or increasing its flow, will require coordinated efforts of funding agencies, professional societies, employers, higher education administrators, faculty, and students. By bringing these stakeholder groups together, the INGenIOuS project aims to generate coordinated proposals not only to adapt and implement promising practices but also to identify and encourage new approaches, including in areas that lack research-supported strategies.

The President’s Council of Advisors on Science and Technology (PCAST) acknowledged in its *Engage to Exce*l report (Holdren & Lander, 2012) that fewer than 40% of students who enter college intending to major in a STEM field actually complete such a degree. But general rates of persistence to a degree are significantly higher: around 60% on average across all disciplines (ACT, 2013). PCAST concluded that retaining more STEM majors is the best way to increase the national supply of STEM workers. A special challenge is to retain underprepared students and those from underrepresented groups (including minorities, women, and first-generation college students) in mathematical sciences courses and programs.

Attracting STEM students is just as important as retaining them. Increasing the pool by attracting more students from traditionally underrepresented groups, while improving readiness and retention for all, can substantially increase the flow of well-qualified mathematical scientists into the workforce. Indeed, *The Mathematical Sciences in 2025* (National Research Council, 2013) urges departments to broaden the class of students they attract—and wish to attract—at all levels, and to identify and adopt priorities for educating these students. The *SIAM Report on Mathematics in Industry* (Society for Industrial and Applied Mathematics, 2012) reaches similar conclusions.

Higher participation of underrepresented groups in the mathematical sciences is important for many reasons, not least to strengthen innovation and creativity within the community (Page, 2007). Foreign-born STEM workers provide some of the needed diversity in the STEM workforce, but it is unlikely that this group can fill gaps indefinitely, especially as global demand for STEM talent increases. For reasons of both economics and of equity, we should increase both global and domestic diversity in the STEM workforce. Women and minorities make up more than half the population; to ignore talent within these subpopulations is both inequitable and wasteful (Carnevale, Smith, & Melton, 2011). In recent years, women received about 57% of *all* undergraduate degrees, but only around 40% of undergraduate degrees in the mathematical sciences. Participation is much lower among underrepresented minorities, who receive less than 12% of all bachelor's degrees awarded in the mathematical sciences. Moreover, the percentage of degrees awarded to women and to minorities declines at the graduate levels. This situation has not improved over the past decade; numbers have remained roughly stable (National Science Foundation & National Center for Science and Engineering Statistics, 2013; Pierson, 2013).

To increase diversity within STEM we must boost awareness and promote understanding of problematic unresolved issues such as implicit bias, cultural stereotypes, and a narrow spectrum of role models (Hill, Corbett, & Rose, 2010; National Academy of Engineering, 2008). Development and dissemination of successful strategies for increasing diversity should occur at all levels of the mathematical sciences pipeline, from K–12 through graduate study.

Curricula and professional training programs require timely updates to reflect current job opportunities for mathematicians and statisticians. The expansion of research opportunities in the mathematical sciences for students as well as professionals adds pressure to rethink both preparation and recruitment. Changes in the types of industries that now hire mathematical and computational scientists, in requirements for these jobs, and in contributions such scientists make in the workplace are described in the *SIAM Report on Mathematics in Industry* (Society for Industrial and Applied Mathematics, 2012). This report also offers suggestions and recommendations for matching higher education curricula to workforce needs. According to *The Mathematical Sciences in 2025* (National Research Council, 2013), mathematicians and statisticians should "engage with STEM discussions going on outside their own community and not be marginalized in efforts to improve STEM education. … Change is unquestionably coming to lower-division undergraduate mathematics, and … the mathematical and statistical sciences community [should] ensure it is at the center of these changes and not at the periphery."

Recent results from the Program for International Student Assessment (PISA) raise concerns about U.S. student performance in mathematics literacy. U.S. high school students performed below the average of students from the 34 Organization for Economic Co-operation and Development (OECD) countries, and only around average for students from all participating countries (http://nces.ed.gov/surveys/pisa/pisa2012/). Boosting postsecondary student success in STEM will be even harder unless the mathematics literacy among K–12 school students improves.

How the INGenIOuS project and workshop came about

The Mathematical Association of America (MAA) and the American Statistical Association (ASA), in partnership with the American Mathematical Society (AMS) and the Society for Industrial and Applied Mathematicians (SIAM), with funding from the National Science Foundation (grant DMS-1338413), brought together representatives of academic institutions, professional societies, government agencies, business, and industry to develop strategies for future investments in training at the graduate and undergraduate levels. The AMS, ASA, MAA, and SIAM—all members of the Joint Policy Board for Mathematics (JPBM)—have collaborated in many ways over the years, but not often with a specific focus on workforce development. The present effort began in summer 2012 when representatives of all four societies populated a committee to advise the NSF on key workforce development issues. The initiative that emerged in the following year came to be called the INGenIOuS project (ingeniousmathstat.org). Its primary goal was to encourage development and implementation of evidence-based improvements to student recruitment, retention, degree completion, and job placement of future professional mathematicians and statisticians.

The advisory committee structured a process by which communities were formed to focus on six major challenge areas, or "themes," related to workforce development: recruitment and retention of students, technology and MOOCs, internships, job placement, measurement and evaluation, and documentation and dissemination. An online panel and forum discussion focused on each of the six themes. These activities led, in turn, to six corresponding white papers (Appendix B).

The white papers and other readings (cited in the References section) were made available in advance of the final project component: a three-day workshop held in July 2013 at the ASA headquarters in Alexandria, Virginia. Prepared with this background information, workshop participants could seek new ways forward, strategize about future investments, and begin designing projects without repeating mistakes and re-inventing successful initiatives.

Details of the workshop's organization, agenda, and schedule appear in Appendix C. The workshop was effectively facilitated by the consulting firm KnowInnovation.

III. Audiences for this report

Workforce issues in general, and the INGenIOuS project in particular, involve many stakeholders, whether as participants or as audiences. Most of the major stakeholder groups were represented at the INGenIOuS workshop itself:

- Funding agencies: National Science Foundation (NSF), National Security Agency, National Institutes of Health
- Professional societies: AMS, ASA, MAA, SIAM
- NSF Mathematical Sciences Research Institutes: Institute for Mathematics and its Applications, Minneapolis
- Business, industry, and government (BIG): major industries (e.g., Boeing, IBM, Procter & Gamble); federal and state agencies (e.g., U.S. Census Bureau, Maryland Department of Natural Resources); healthcare organizations (e.g., Cincinnati Children's Hospital and Medical Center)
- Academia: Universities and colleges (public and private, small and large, teaching- and research-focused, community colleges), graduate students, faculty, and administrators.

Not every important audience for this report was represented at the workshop. K–12 teachers, for example, were minimally represented, as the workshop focused on postsecondary education. No undergraduate students and only a few graduate students (representing both pure and applied programs) were present; they, too, represent important constituencies. Students who enter careers in education, for instance, can directly influence workforce developments in both the short and long term. Other mathematical sciences students will populate the next generation of workers in business, industry, and government.

Below we identify key constituencies and relevant workforce-related issues and messages that arose at the workshop.

K–12 educators. Jobs of the future will require solid problem-solving skills as nurtured by study in the mathematical sciences. Students should appreciate that mathematics and statistics skills and competencies are linked to future career opportunities that far exceed the limited stereotypical options of teaching, accounting, and engineering.

The teacher preparation community. Only minimally represented at the workshop, this group can lead sustainable changes in attitudes about and awareness of careers in the mathematical sciences. Additional teacher educators might participate in future workforce-related discussions through their professional organizations (e.g., the Association of Mathematics Teacher Educators) or through the Conference Board of Mathematical Sciences (CBMS), whose members include the AMS, ASA, MAA, SIAM, the National Council of Teachers of Mathematics (NCTM), and others.

Community college faculty and administrators. Community colleges are increasingly important in workforce preparation and in early stages of higher education for STEM majors. Mathematical and statistical competencies taught in the first two years are required for both purposes. The American Mathematical Association of Two Year Colleges (AMATYC), also a member of CBMS, should participate in these discussions.

Undergraduate students. A student leaving high school with strong skills and ongoing interest in mathematics or statistics should expect to continue studying those areas in college; colleges and universities should provide information about career opportunities demanding these skills.

Graduate students. While many Ph.D. students in mathematics and statistics will aim for teaching and research careers in academia, many others will pursue careers in the business, industry, or government (BIG) sectors. Master's degree (both M.S. and M.A.) students in mathematics and statistics are especially likely to enter the non-academic workforce. All graduate students should expect their programs to prepare them for the full gamut of job options inside and outside academia.

College and university faculty. Faculty members should appreciate and encourage BIG careers as viable alternatives to the academic teaching and research tracks. They should also collaborate with BIG employers to develop partnership programs. Not every faculty member should participate in such initiatives, but all should value these efforts by encouraging student participation and by appreciating such work done by colleagues.

Department chairs. Chairs of mathematics, statistics, and cognate departments should help ensure that students at all levels are prepared to contend for jobs as mathematicians and statisticians both inside and outside of academia. A chair can encourage, promote, and support curricular and co-curricular activities that improve workforce preparation. The chair's support is crucial to faculty members who promote non-academic workforce options and programs; their efforts should be recognized in hiring, compensation, and tenure and promotion policies.

Academic administrators. Administrative support is necessary for the changes recommended in this report to have broad and sustainable impact. Deans and provosts are especially vital to this effort. Operating within the broader academic framework in which these initiatives will develop, these administrators are uniquely positioned to implement policies that support efforts to increase the nation's supply of mathematical sciences professionals.

BIG partners. Organizational needs of business, industry, and government must be understood and appreciated within academia if workforce development components of mathematical sciences programs are to be improved. BIG partners should begin talking with faculty and chairs in local departments about partnerships and collaborations.

Professional societies. The mathematical sciences professional societies are well positioned to foster communication and cooperation among academic and BIG mathematics and statistics professionals. News outlets for members of professional societies (e.g., *AMS Notices, AMSTAT News, MAA FOCUS, SIAM News*) should intentionally stimulate further discussion of workforce development issues among members of their societies. Since education in the mathematical sciences is critical to all STEM areas, related disciplinary societies such as the American Society for Engineering Education (ASEE), the Association for Computing Machinery (ACM), and the Institute of Electrical and Electronic Engineers (IEEE) should also participate in workforce-related conversations.

Funding agencies and foundations. Funding to develop the talent pool in the mathematical sciences will support the next generation of mathematicians and statisticians. While funding agencies have a strong history of supporting the development of programs that provide student research experiences, less developed models exist to provide workforce development experiences; additional support is needed for these. Financial support for research is separated from support for educational development within current funding structures, but the health of the mathematical sciences workforce depends on increasing the recruitment of high school students with mathematical skills and interest and retaining these students once they enter post-secondary programs in the mathematical sciences.

IV. Workshop outcomes: Threads, action examples, and recommendations

The six main themes mentioned above (recruitment and retention, technology and MOOCs, internships, job placement, measurement and evaluation, documentation and dissemination) and associated white papers (Appendix B) formed the foundation for initial discussions at the workshop. Discussions ranged widely, but a variety of issues soon coalesced as a collection of overlapping topics related to workforce development. These were organized into six main "threads":

Thread 1: Bridge gaps between business, industry, and government (BIG) and academia

Thread 2: Improve students' preparation for non-academic careers

Thread 3: Increase public awareness of the role of mathematics and statistics in STEM and non-STEM careers

Thread 4: Diversify incentives, rewards, and methods of recognition in academia

Thread 5: Develop alternative curricular pathways

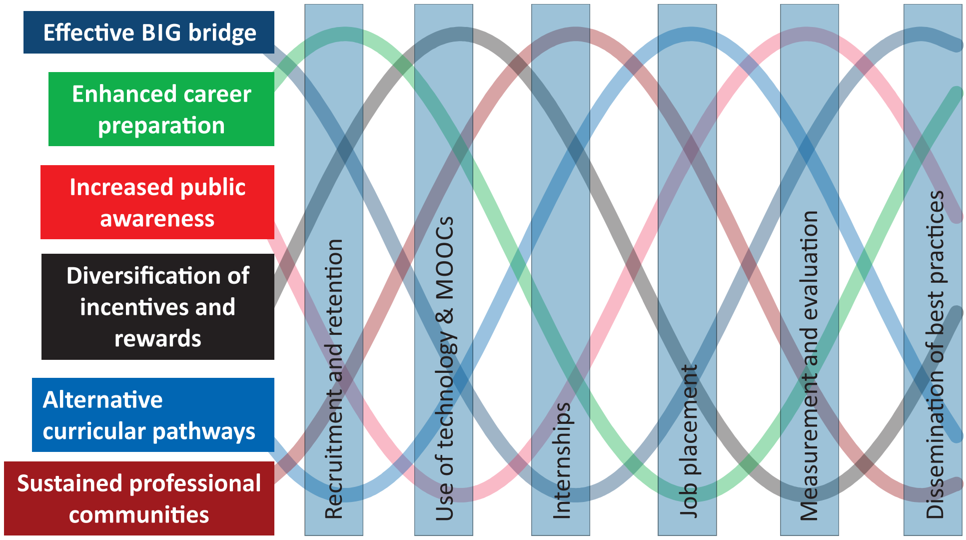
Thread 6: Build and sustain professional communities.

The original six themes were not abandoned; they ran throughout the emergent threads, which are themselves tightly intertwined. The following figure hints at this relationship.

In what follows, we elaborate on each thread, offering, where possible, both action examples (initiatives now underway or feasible in the short term) and recommendations for future initiatives as well as suggestions for who should undertake them. Some initiatives address several different issues and might have appeared in multiple threads; for brevity we include each initiative under only one thread. Additional details of discussions surrounding these initiatives can be found in Appendix D.

Thread 1: Bridge gaps between BIG and academia

Elaboration. The need to acknowledge and address the interests and requirements of employers in business, industry and government in the educational experiences in academia was a recurring topic during the workshop. Various strategies were suggested to forge new



and strengthen existing relationships among academic and BIG professionals, and to promote collaborations among academic and BIG partners. Such collaborations might focus, for example, on connecting students to internship opportunities in BIG, developing opportunities for student research experiences onsite with BIG employers, or disseminating information to students regarding the mathematics and statistics skills and competencies needed for careers in BIG. Such efforts would increase the pool of students with the interest, skills, and experiences necessary to embark on a career in BIG.

Action examples and recommendations. Several initiatives for linking BIG organizations to academia now exist or seem achievable in the short term:

- An exchange program in which academic faculty members work four days each week on campus and one day onsite in a BIG setting. BIG professionals in turn would serve as visiting lecturers at higher education institutions.
- An advisory board that includes data and computational scientists for programs in biology and medicine, materials science, climate and oceanography, finance, social sciences, etc.

Ensuring progress toward a well-supplied, sustainable pipeline of professional mathematicians and statisticians will require action and contributions from stakeholders in BIG and in academic settings. Workshop participants recommended some key “bridging” initiatives:

- Academic programs should create and maintain detailed databases on career trajectories of alumni. Social media (LinkedIn is one current example) might be useful. Alumni should be invited back to campus to interact with students.
- Academic programs and BIG employers should cooperate to create databases of internship opportunities for students of mathematics and statistics.
- Academic programs should identify and partner with BIG professionals willing to come to campus and interact with students.

- The mathematical sciences community should work to increase the spectrum of BIG employers who recruit on campuses and at mathematical sciences conferences.
- BIG and academic mathematicians and statisticians who actively participate in professional conferences (e.g., MAA MathFest, the Joint Mathematics Meetings of the AMS and MAA, and the Joint Statistical Meetings) should capitalize upon these opportunities for communication to promote mutual understanding of the requisite skills for success in BIG careers.
- Academic programs should establish BIG advisory boards composed of alumni and local BIG employers in order to inform curricular enhancements and to connect students to internships and job opportunities.
- NSF-supported mathematical institutes should organize programs and activities to promote BIG-academia collaborations, sharing of best practices, and connecting students with BIG employers.

Thread 2: Improve students' preparation for non-academic careers

Elaboration. A second recurring focus of workshop discussions was the need to improve career preparation for all students of mathematics and statistics while emphasizing the centrality of their disciplines to the broader STEM enterprise. Better career prospects in mathematics and statistics can boost recruitment and retention efforts in the short term. In the long term better preparation can increase the number of graduates entering the workforce well equipped for careers that require strong skills and expertise in mathematics and statistics.

Curricular change is needed, and that will require changes in some faculty members' perceptions of BIG careers for students in the mathematical sciences. Some faculty advisors convey disappointment when students pursue non-academic career paths. Such views may simply reflect unfamiliarity with non-academic career options for mathematical sciences graduates. The fact that agencies such as the Bureau of Labor Statistics do not classify some workers, such as mathematical scientists working in the education and healthcare sectors, as STEM professionals may also contribute to confusion about available opportunities. The academic community should seek to identify and correct misperceptions, whatever their causes.

An ASA workgroup recently produced recommendations for master's degree programs in statistics (www.amstat.org/education/pdfs/PMSSS.pdf and magazine.amstat.org/wp-content/uploads/2013an/masterworkgroup.pdf). Interviews with recent graduates and employers indicated that the most successful graduates possess content knowledge and skills in statistics and mathematics, as expected. But they were also good communicators, could function effectively on interdisciplinary teams, and could adeptly propose computational answers to research questions. The report, endorsed by the ASA Board of Directors, can guide departments interested in revising curricula to better integrate such skills.

Improving students' career preparation in mathematics and statistics will benefit institutions directly. Alumni who succeed in BIG careers are prime candidates to serve on advisory boards and support scholarships, internships, and experiential learning opportunities for students as potential future employees. These alumni also serve as ambassadors for the mathematical sciences to the general public. Better career preparation can both boost recruitment and retention efforts in the mathematical sciences and, ultimately, increase the number of graduates entering the workforce well equipped for careers that require strong mathematics and statistics skills.

Action examples and recommendations. Several initiatives for improving students' preparation for non-academic careers now exist or seem achievable in the short term:

- Work Experiences for Undergraduates (WEU) programs and Work Experiences for Graduate Students (WEG) programs can be modeled after successful Research Experiences for Undergraduates (REU) programs—but differing in that WEU and WEG students would work onsite for the BIG employer, not on a college or university campus. Embedded in BIG environments, students could participate in BIG-style research.
- A comprehensive online source of career information, including references to existing online materials. Excellent material exists to begin the project:
  - AMS careers pages:
    www.ams.org/profession/career-info/math-work
  - ASA careers pages:
    www.amstat.org/careers/
    www.amstat.org/careers/whatdostatisticiansdo.cfm
    www.amstat.org/careers/whichindustriesemploystatisticians.cfm
  - MAA careers and profiles pages:
    www.maa.org/careers/
    www.maa.org/careers/career-profiles/we-do-math
    www.ams.org/profession/career-info/math-work
  - SIAM careers and Math Matters pages:
    www.siam.org/careers/
    www.siam.org/careers/thinking/pdf/brochure.pdf
    www.siam.org/careers/matters.php
    www.siam.org/careers/sinews.php
  - Why Do Math site:
    www.whydomath.org
  - We Use Math site:
    www.weusemath.org
- Training for faculty on evolving workforce requirements and the range of career opportunities outside academia.
- Collaborations among mathematical sciences departments, campus career centers, and alumni relations offices to inform students who have not chosen further study in the mathematical sciences about career options in BIG.

Workshop participants identified future action agendas for various stakeholder groups to improve career preparation:

- Professional societies, funding agencies, institutes, and foundations should support efforts among faculty and BIG professionals to form relationships and begin collaborations.
- The mathematical sciences community should develop effective metrics and assessment tools for evaluating initiatives. This effort might begin with the collection of baseline data on faculty and student awareness of possible career options.
- Faculty should ensure that students hear more about new applications of mathematics and statistics to such fields as weather prediction and cancer research.
- Academic institutions should support faculty efforts to develop local training and research opportunities in collaboration with BIG employers. Such efforts would increase faculty and student awareness of and students' preparation for existing career opportunities.

We acknowledge the need to consider what K–12 teachers, guidance counselors, and students require as information about and early preparation for mathematical sciences career options. Such issues are outside the scope of the INGenIOuS project, but must be addressed if the larger workforce goals outlined in such reports as *Engage to Excel* (Holdren & Lander, 2012) are to be met. Potential next steps include developing targeted resources for the K–12 sector and building local and regional networks for outreach to schools.

Thread 3: Increase public awareness of the role of mathematics and statistics in STEM and non-STEM careers

Elaboration. Huge deficits exist in public awareness (here we use "public" in the broadest possible sense, comprising not only the "general public" but also employers, students, tertiary faculty and administrators, and K–12 teachers and administrators) of careers with links to STEM disciplines as a whole, and more specifically of the importance of mathematics and statistics for both STEM and non-STEM careers. Public awareness should extend beyond the sexy "CSI-type" jobs, like crime scene investigators and medical examiners, to include other options that require a strong foundation in mathematics and statistics, like finance, economics, and medicine. For example, how many academic mathematicians and mathematical sciences students, let alone the public at large, realize that partial differential equations play a crucial role in planning facial reconstruction surgeries? (www.siam.org/careers/pdf/facial.pdf.) How many members of the public appreciate the centrality of the principles of statistical experimental design in clinical trials of new therapies, or the importance of statistical survey sampling for evaluating our nation's economic health? How many know that serious mathematics underlies delivery truck routing?

Action examples and recommendations. Several initiatives for building public awareness of the importance of the mathematical sciences for all careers now exist or seem achievable in the short term:

- April is recognized each year as Mathematics Awareness Month by the Joint Policy Board for Mathematics. Throughout the month, attention is focused on the role of the mathematical sciences in a broad swath of scientific, societal, and other public issues, including those related to workforce development.

- Five statistics societies, including ASA and the Institute of Mathematical Statistics, designated 2013 as The International Year of Statistics and led a worldwide celebration to recognize the contributions of the statistical sciences.
- Over 100 professional societies, universities, research institutes, and other organizations dedicated 2013 as a special year for the Mathematics of Planet Earth (MPE 2013). One goal of MPE 2013 was to increase public awareness of the essential role of the mathematical sciences in meeting environmental and other challenges facing our planet.
- A planned public relations campaign involving the Washington, D.C., public transit system will include messaging such as "Math Without Words" (see www.lulu.com/us/en/shop/james-tanton/math-without-words/paperback/product-12303272.html and www.lulu.com/us/en/shop/james-tanton/math-without-words/paperback/product-12303272.html) and a website with solutions posted.
- Statisticians and journalists have partnered to produce audio programs exploring "the statistics behind the stories and the stories behind the statistics" in an attempt to increase public awareness of everyday experiences with data (see www.statsandstories.net).

Workshop participants also recommended long-term action agendas for various stakeholder groups in building public awareness:

- The mathematical sciences community should establish effective, high-impact platforms for distributing relevant information. Professional societies, funding agencies and foundations, and BIG employers can assist with such initiatives under the umbrella of their outreach, public relations, or marketing efforts. Traditional forms of communication should be re-imagined and new and emerging options explored. Messaging might highlight:
    - Cutting-edge work in the mathematical sciences with immediate impact on society.
    - The fact that STEM knowledge and skills, particularly those gained from study in the mathematical sciences, are key to careers not only in STEM fields, but across the employment spectrum.
    - The fact that work in the mathematical sciences, for all its power and applications in other fields, is also a creative, exciting endeavor in its own right.
- Funding agencies and foundations should solicit and support projects that include components designed to increase public awareness.
- Academic institutions should reward and support mathematics and statistics faculty who communicate to broad audiences the special importance and application of their work.

- BIG employers should encourage their own mathematicians and statisticians to help increase public awareness of the importance of the mathematical sciences to society as a whole.

Thread 4: Diversify incentives, rewards, and methods of recognition in academia

Elaboration. A strong tradition of established reward structures exists in academia. The tenure system now practiced in higher education, for example, dates back to the 19th century. Academic institutions and mathematical sciences departments should nudge their ever-evolving systems of reward and recognition to include support for the preparation of more students to meet 21st century workforce demands, while maintaining high academic performance standards for faculty and students. Not all faculty members should be expected to participate in the same professional activities. Rather, a well-balanced mathematical sciences program offering a bachelor's degree or above should include faculty with a variety of interests, some focused primarily on discovery research (in, e.g., classical mathematics, both pure and applied; theoretical statistics; mathematics or statistics education); some focused on applied, collaborative or interdisciplinary areas; and others on teaching and preparation for careers both inside and outside of academia.

Recommendations. No short-term action examples for this thread were identified at the workshop. Focusing instead on the longer term, workshop participants proposed action agendas for various stakeholder groups in diversifying incentives, rewards, and methods of recognition.

- Mathematics and statistics departments should diversify the professional activities that are valued as criteria for rewards and recognition, including tenure and promotion incentives. The range of rewardable activities should include scholarly work (currently the most traditional dimension rewarded), curricular innovation, the use of evidence-based pedagogies, collaborations with BIG employers, supervision of undergraduate research experiences, and the scholarship of teaching and learning.
- BIG employers should reward their mathematicians and statisticians who recognize and accept responsibility for the vital parts they might play in the preparation of mathematics and statistics students.
- Professional societies should find ways to recognize exemplary programs and provide support for replication or adaptation of exemplary practices.

Thread 5: Develop alternative curricular pathways

Elaboration. In some mathematics and statistics degree programs, career preparation is merely an afterthought, inserted near the end of the coursework, if at all, or included on a faculty advisor's list of office-hour topics. Too few programs help students explore career options in depth, and too few offer curricula designed to prepare students for careers in BIG as well as careers in academia. Traditional curricula in the mathematical sciences have been dominated by upper level majors' courses focused on theory, with shorter shrift given to applications that reflect the complexity of problems typically faced in BIG environments, and to appropriate uses of standard BIG technology tools. While current consulting or data practicum courses in statistics departments and modeling courses in mathematics departments might provide a taste of work on real problems, these problems are often sanitized versions of the complex problems encountered in real life. The computation requirements that are sometimes part of mathematics and statistics majors provide an introduction to scientific computing constructs, but requirements should be expanded to help students prepare for the big data found in BIG contexts by including more mathematical and statistical modeling, data analysis, visualization, and high performance computing. Departments should integrate appropriate modeling scenarios and applications through, for example, guest lectures and student projects.

Alternative curricular entry points (e.g., courses other than freshman-level algebra or beginning calculus) and pathways to undergraduate and graduate degrees should be developed. They could at once broaden students' awareness of career options and build the mathematical competencies, computational facility, and career success skills such as written and oral communication and teamwork required for rapid transition into the workforce.

Mathematical sciences departments should maintain sound disciplinary training, but also modernize programs and curricula to better capitalize on the interplay of mathematics and statistics with a broad spectrum of career options. Mathematical sciences students recognized as well-prepared for the workforce should graduate with broad disciplinary knowledge and computational skills, understanding of the foundational nature and applicability of the mathematical sciences to other disciplines, direct experience solving problems from BIG settings using appropriate technology and related tools, and communication and teamwork skills valued in BIG settings. Facilitating this preparation will require mathematical sciences programs to develop diverse curricular pathways, build strong links to other disciplines and BIG employers, and secure strong faculty and institutional commitment. But fully addressing the curricular and experiential needs of mathematical sciences students will require broad commitment from mathematical sciences faculty to collaborate with colleagues from other disciplines and BIG employers.

Action examples and recommendations. Several initiatives for diversifying curricular pathways now exist or seem achievable in the short term:

- MAA's Committee on the Undergraduate Program in Mathematics is preparing its roughly decennial Curriculum Guide (anticipated release in 2015). The Guide includes recommendations for courses and programs in the mathematical sciences; we expect the new edition to feature many recommendations consistent with this report.
- A new M.S. in data science that merges statistics, computer science, and engineering will launch in 2014 at Columbia University.
- The theme of *Modeling across the Curriculum* was explored during an August 2012 SIAM–NSF workshop. The workshop report (www.siam.org/reports/modeling_12.

pdf) includes several recommendations for undergraduate programs. SIAM is also planning professional development workshops, aligned with Moody's Mega Math Challenge, for high school teachers in response to the recommendations (http://m3challenge.siam.org).

- New degree programs are being developed in data analytics, incorporating elements of modeling, computational science, applied statistics, and data mining. Brigham Young University will debut such a major in fall 2013; Clarkson University is developing an interdisciplinary undergraduate minor involving the mathematical sciences and the business school.
- Alternative curricula aimed at both students and in-service workers are being developed in biomedical informatics at the University of Minnesota, Rochester.

Workshop participants identified action recommendations for various stakeholder groups as next steps toward diversifying curricular pathways:

- Funding entities should support more curricular experiments. The NSF program Expeditions in Training, Research, and Education for Mathematics and Statistics through Quantitative Explorations of Data (EXTREEMS-QED) is one example. Partnerships between NSF's Division of Mathematical Sciences and its Division of Undergraduate Education could open new possibilities.
- Professional societies should act on several fronts:
  - Offer workshops, professional development programs, and curricular guidance to support recommendations in this report.
  - Include with curriculum recommendations up-to-date guidelines for technology tools best suited to prepare students for BIG careers.
  - Facilitate dissemination of curricula shown to provide effective preparation for careers, inside and outside academia, that require strong mathematics and statistics skills.
  - Support dissemination of new teaching ideas through journals, short courses, and other channels.
- The mathematical sciences community as a whole should study alternative models for academic credit through MOOCs, internships, and other forms of experiential learning.
- Faculty should consider alternatives to standard algebra- or calculus-based entry points to majors in the mathematical sciences, pilot various options, and assess outcomes, including mathematical sciences degree attainment and entry into the workforce.
- Graduate programs should systematically introduce graduate students to career opportunities outside academia and expectations of employers. ASA reports referenced above (www.amstat.org/education/pdfs/PMSSS.pdf and magazine.amstat.org/wp-content/uploads/2013an/masterworkgroup.pdf) offer examples.

- Institutions should establish or improve new or existing professional master's degree programs that emphasize applied, computational, and interdisciplinary mathematics and statistics, and combinations of these with business analytics, biology and medicine, materials science, climate and oceanography, finance, social sciences, and other fields.
- Administrators and department chairs should support and reward curricular innovations and experimentation as well as full-scale implementation. Continual assessment and gathering of additional data to evaluate various implementations of evidence-based curricula and teaching methods should be special priorities.

Thread 6: Build and sustain professional communities

Elaboration. INGenIOuS workshop participants repeatedly expressed the need for mechanisms to link the national community of professionals involved in workforce development and thereby facilitate information and resource exchange, collaboration and support, and networking. Such a network should include stakeholders from academia, BIG employers, professional societies, and funding agencies and foundations. Using the full gamut of virtual and in-person communication methods and tools available, the envisioned network would facilitate dissemination of best practices; assist faculty in incorporating current technology tools at the undergraduate and graduate levels; and support local efforts to recruit and retain students, assess and evaluate programs, identify internships, and improve job placement.

Action examples and recommendations. Several initiatives for creating sustained professional communities now exist or seem achievable in the short term:

- An electronic listserv or discussion board for departments in the mathematical sciences with information about workforce issues. Discussion and interactions within these communities might focus on topics such as career options and preparation for students in the mathematical sciences; specific opportunities for BIG internships and jobs, experiential learning, and professional development for students and faculty; curricular resources; evidence-based practices; collaboration opportunities; implementation issues; network development; student recruitment and retention; assessment and evaluation.
- Workforce-related sessions and workshops, including the stand-alone and virtual varieties as well as those held in conjunction with professional society conferences.
- Workshops hosted by mathematical institutes to share best practices and build community among workforce-interested participants.
- On-site, multi-day sessions for academics at BIG entities during which they join a team working on existing problems.

The INGenIOuS project itself might serve as the genesis of a community like those suggested above, though a broader spectrum of participants is needed. Representatives from various constituent groups could take responsibility for specific aspects of community building. Quickly implementing basic components, such as a listserv, would help expand the community and boost its efforts. INGenIOuS project participants from the various sponsoring professional societies have already begun to consider how to use existing society conferences and events to spread the word, but additional mathematical sciences professionals will need to propose sessions and workshops, share best practices and ideas, and reach out to related organizations. Building an effective and sustainable community will require sustained effort in both the short and long term, and therefore the emergence of a committed and capable leadership team. People with existing experience and information are best able to contribute to these efforts in the short term, but passionate and engaged leaders must step forward to ensure that efforts continue to develop, expand, and thrive.

V. Conclusion

Research suggests (see, e.g., Kania & Kramer, 2011) that, in achieving significant and lasting change in any area, a single coordinated effort supported by major players from all existing sectors is more effective than an array of new programs and organizations. A key strategy is to invest in the creation of a strong backbone organization, develop common agendas and language, work toward agreed upon metrics of success, facilitate communication, and support evidence-based modifications of existing programs and efforts. The INGenIOuS project demonstrated that stakeholders across the mathematical sciences community can successfully collaborate on workforce development issues. It highlighted existing efforts and drew on the collective wisdom of a diverse group of participants. Perhaps the INGenIOuS platform, suitably enlarged or modified, can launch future initiatives.

We acknowledge that changing established practices can be difficult and painful. Changing cultures of departments, institutions, and organizations can be even harder. But there is reason for optimism. In mathematical sciences research we are always willing, even eager, to replace mediocre or "somewhat successful" strategies with better ones. In that open-minded spirit we invite the mathematical sciences community to view this call to action as a promising opportunity to live up to our professional responsibilities by improving workforce preparation.

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