INGenIOuS Project

Report on July 2013 Workshop

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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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 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.

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 recommendation in each area are discussed in detail in the body of the report; following are brief summaries.

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[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.

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 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, it 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 – regarding careers with links to STEM disciplines and 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 broaden their long-established systems of reward and recognition to include support for 21st century career preparation of students while maintaining high academic performance standards for faculty and 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 inside 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 and better serve students in general.

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.

Change is difficult but worthwhile. We acknowledge that changing established practices can be difficult and painful. Changing the culture of departments, institutions, and organizations can be even harder. In mathematical sciences research, by contrast, we are always willing, even eager, to replace mediocre or "somewhat successful" strategies with better ones. In that optimistic 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.

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, including recently, for example, in *The Chronicle of Higher Education* (Anft, 2013) and on WVTF Public Radio (Hausman, 2013). Indeed, the total number of STEM graduates roughly equals the total number of available STEM positions annually (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 at a faster rate 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. Indeed, 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 adds 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, and statisticians are all different. And 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 a strong foundation in mathematics and/or 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 – 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 supply of U.S. 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) makes similar points.

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; failure to access 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. The situation has not improved over the past decade; it has 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 provides additional impetus to rethink both preparation and recruitment. Changes in the types of industries that now hire mathematical and computational scientists, requirements for these jobs, and 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 on the mathematics literacy section of this assessment. 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 at about the average when students from all participating countries are included (http://nces.ed.gov/surveys/pisa/pisa2012/). Boosting postsecondary student success in STEM will be even more of a challenge 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. (See 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), which includes as members 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 and that colleges and universities will provide information about career opportunities demanding these skills.

Graduate students. 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 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 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 recommendations 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

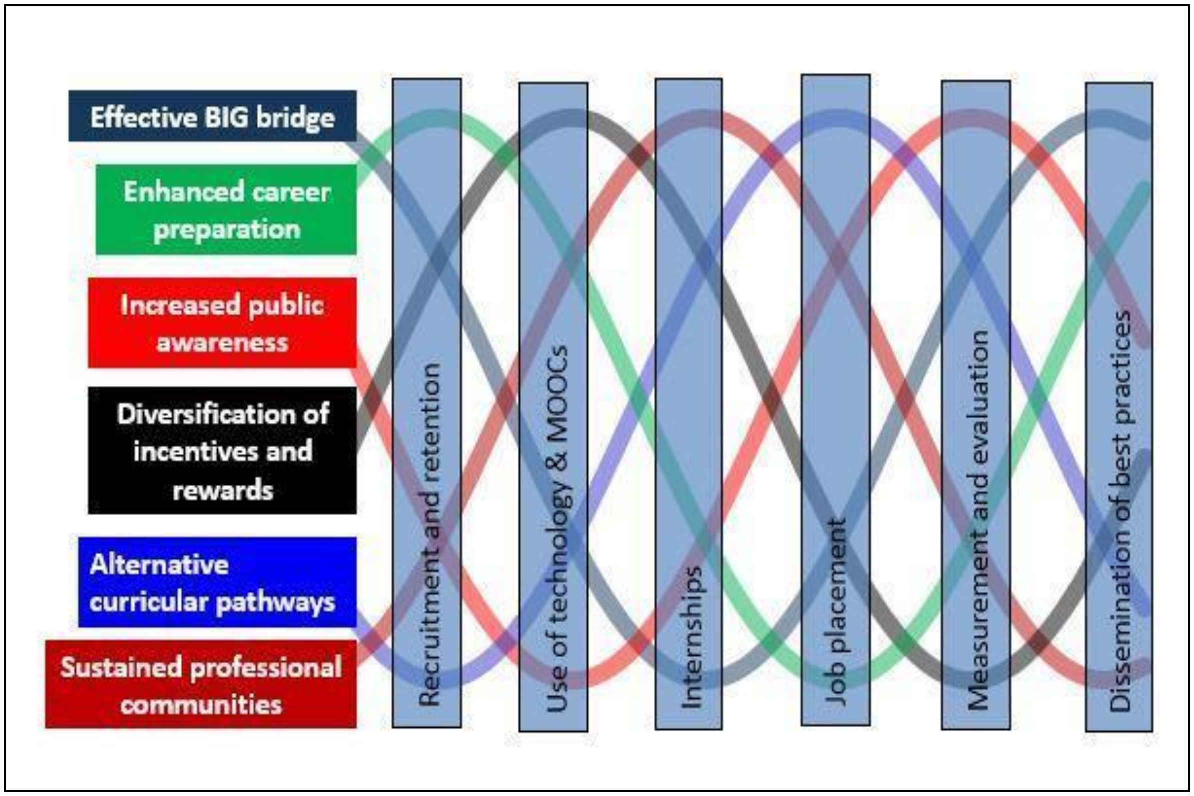
Thread 3: Increase public awareness of the role of mathematics and statistics in STEM and non-STEM careers

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 regarding who should undertake them. Some initiatives address several different issues and might have appeared in multiple threads. For the sake of brevity, we chose to include each initiative under a single 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 a broad array of stakeholders. 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 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 also 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 it 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, 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
  - SIAM careers and Math Matters pages:
    www.siam.org/careers/thinking/pdf/brochure.pdf
    www.siam.org/careers/matters.php
    www.siam.org/careers/
    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* [12] 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 IMS, 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 were identified at the workshop for this thread.   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, 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 after-thought, 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 should be expanded to help students prepare for the big data encountered in BIG contexts by including more mathematical and statistical modeling, data analysis, visualization, and high performance computing   Departments should, wherever appropriate, integrate 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 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, and we anticipate the new edition will 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. NSF's 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, etc.
- 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 a mechanism 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 the culture of departments, institutions, and organizations can be even harder. In mathematical sciences research, by contrast, we are always willing, even eager, to replace mediocre or "somewhat successful" strategies with better ones. In that optimistic 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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APPENDIX A

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APPENDIX B

White papers

Recruitment and Retention White Paper

William Yslas Vélez and Judy L. Walker

July 9, 2013

Recruitment and Retention issues naturally fall into two separate categories, undergraduate and graduate. The bulk of this document will be separated into the two categories, but we begin with a discussion of diversity.

The demographics of this country are changing and it is in the best interest of the mathematical community that our profession reflects this change. It currently does not. According to 2010 census data, 12.6% of the U.S. population is black/African-American and 16.4% is Hispanic or Latino. According to the 2011 AMS Survey on the Profession, there were 802 Ph.D.s in the mathematical sciences granted to U.S. citizens in 2010-2011 (the most recent year for which data is available). Only 21 (2.6%) of these went to blacks/African Americans and only 20 (2.5%) of these went to Hispanics/Latinos. More than half of the U.S. population is female and yet only 228 (28%) of these Ph.D.s went to women.

It is imperative that our profession do a better job with diversity. The big question is how to accomplish this. Across the country we see programs, at both the undergraduate and graduate levels, which have had success with certain groups. Oftentimes, these successes have been recognized through the Presidential Awards for Mentoring (PAESMEM), so there is a ready-made resource for departments to learn from these activities and modify them to their needs. Many of these programs are funded by NSF, but NSF could go further in promoting diversity in our profession. Although NSF specifically uses Broader Impact as one of its two review criteria, and, in particular highlights “full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM)” in their Grants Proposal Guide as one of the possible examples of broader impacts, the mathematical community as a whole does not always give this issue the attention it deserves.

However, there is one traditionally under-represented group for whom little progress has been made, and that is the Native American population of this country. Though Native Americans comprise only a very small percentage of our country’s population overall, several states have strong concentrations of Native Americans and these concentrations are not appropriately reflected in the mathematics departments at the colleges and universities of these states. Native American mathematics majors, graduate students and faculty are so small in numbers as to be almost invisible. Since this group lacks representation in the mathematical community, its voice is not heard and few speak in its stead.

NSF should make every effort to address this serious and deplorable absence of the Native American population in the mathematical enterprise in the United States. The problems associated with addressing the needs of Native American students are complex. Some of these students have grown up in reservations (There are still boarding schools on some of these reservations.), while others have been raised away from tribal lands. Some reservations have tribal colleges but very few mathematics majors come from these institutions. Strengthening the educational system on reservations schools is certainly called for but represents a significant investment in ideas and funds. One idea that could be implemented is to formulate a plan to have Math Circles established on reservations. Tatiana Shubin, San Jose State University, recently spent her sabbatical leave on the Dine reservation attempting to carry out such an activity.

There are undoubtedly many Native American students attending our universities, but clearly they are not opting for the mathematics major. Though NSF can provide funds to support innovative ideas to increase this representation, the mathematical community is responsible for generating those ideas.

Herein lies the problem of increasing diversity in the mathematical sciences more generally. It is really up the mathematical community to first of all resolve that the traditionally underrepresented populations need to participate in the mathematical enterprise. Moreover, it is the responsibility of departments to increase the number of mathematics majors from traditionally underrepresented groups. Many mathematics/statistics departments complain that they do not get enough applications from these groups for their graduate programs and for faculty positions. Are these same departments part of the problem? If these departments are not producing undergraduate mathematics majors from these groups, then this situation adds to the lack of applications for graduate programs and faculty positions. Perhaps departments should examine their undergraduate programs, create baseline data on the number of students receiving bachelor's degrees from traditionally underrepresented groups, and then develop plans to increase these numbers.

Undergraduate Recruitment and Retention

Departments often have special courses for incoming students, courses that are designed to encourage students to take more mathematics and to add the mathematics major. Mathematicians are of two minds in this arena: some want to stress the beauty and cohesiveness of mathematics, while others think that it is the applications of mathematics that will entice students to the further study of mathematics. The truth, however, is that tens of thousands of students take the calculus sequence and a myriad collection of other mathematics courses. These regular mathematics courses must be viewed as vehicles to encourage the continued study of mathematics. The most important tool that mathematicians have to entice students into the continued study of mathematics is the mathematics that we teach, but it must be taught in an engaging manner and with a concern for student success.

1. The transition from high school to college

Most high school teachers and students view the mathematics major as leading to one career: high school teacher. This is a stereotype that must be changed if we are to increase the desirability of the mathematics major to a larger number of students. The role of mathematics has changed dramatically over the last few decades. The growth in computing power has made the use of mathematical models more prevalent, and mathematical analysis is now employed in a wide range of fields. A more concerted effort should be made to educate the K-12 community, and for that matter the nation, about this dramatic change. The power of the entertainment industry and the media should be viewed as an asset to the mathematics community as it develops ideas to educate the community at large on the importance of mathematical training.

Academic mathematicians have traditionally been unaware of the changes in the applicability of mathematics to other areas. There is still a prevalent attitude among academic mathematicians that the main career paths for mathematics majors are high school teaching or graduate programs within the mathematical sciences. Many graduate academic programs outside of mathematics would like students to have a more serious mathematical background. Encouraging students to add the mathematics major or minor to their current program of study would serve to better prepare them for their future career choices.

Mathematics holds a unique role in university education. Mathematical training not only provides the problem-solving mindset and the attention to detail that is so important, but it also provides the mathematical tools to implement those problem-solving strategies. These two aspects of mathematics, especially when combined with skills learned in computer science courses, prepare mathematics majors for a wide variety of employment opportunities as well as for graduate study outside of the mathematical sciences.

2. Community colleges

Although we had neither expertise on our panel nor mention from the community of the topic of community colleges, this topic is too important to be omitted from this discussion. Community colleges and universities should at a minimum establish articulation agreements to ease the process of transferring from one institution to the next.

We cannot provide a good model here but we encourage discussion as to how to increase the number of community college students who transfer to universities as mathematics majors. This discussion could entail how to increase communication between faculty at the two institutions so that each better understands the issues that the other academic unit faces. NSF could encourage proposals for educational projects that would be jointly carried out by universities and neighboring community colleges. For example, projects that aim to transform how certain entry-level mathematics courses are taught could be conducted jointly by a university and a community college, thus easing the transfer process for students moving from the community college to the university not only in mathematics but in a wide range of STEM areas. Additionally, universities that run summer REU sites could consider running that activity, either totally or partially, at a local community college and faculty with appropriate funding from NSF could allow community college faculty to participate. In fact, NSF might encourage proposals for REU sites from universities that would include community college faculty in a support role. Many students who earn a Master's degree in mathematics often seek employment in the local community college district of the university, so there is a ready-made contingent of community college faculty available.

As was mentioned earlier, high school faculty do not know of opportunities for students with BS degrees in mathematics; the same is most likely true of community college faculty. If these faculty do not know of such opportunities, they will likely not encourage their students to pursue further mathematical studies. This factor alone could be one of the major reasons students do not transfer as mathematics majors. After all, there are plenty of students from community colleges who transfer as engineering and life science majors.

3. Retention

<u>The structure of the mathematics major</u>

The structure of the mathematics major has a tremendous effect on the ability of the program to retain mathematics majors. The conventional mathematics major includes upper division courses in advanced calculus, abstract algebra, linear algebra and complex variables, and these courses have traditionally prepared students for graduate study in mathematics. However, graduate study in mathematics has morphed into graduate study in the mathematical sciences, encompassing traditional programs in mathematics as well as in applied mathematics, statistics, and biostatistics. Moreover, mathematically trained students are highly sought after in a wide variety of academic fields.

Many successful programs offer different course options at the upper division level. These options are designed with student goals in mind. Is the student joining the workforce or pursuing graduate study? If the student is pursuing graduate study, will it be in the mathematical sciences, the life sciences, business, engineering, or some other field? Given the pervasive use of data in society, incorporating a programming requirement for mathematics majors serves to increase the opportunities for mathematics majors.

Of course, offering different options in an undergraduate program necessitates having more courses offered, which can place a strain on departmental resources. When departments have small numbers of mathematics majors, it can be difficult to offer several different upper division courses. However, the mathematics department can seek to work with other academic units on its campus to create options within the mathematics major that are attractive to these other units. Such options could encourage students whose primary interests lie in other fields to add mathematics as an additional major.

<u>Integrating mathematics majors into the scientific life of the country</u>

A mathematician has learned a substantial amount of mathematics, has applied that knowledge to solve problems, and has communicated mathematical ideas to others. Moreover, mathematicians form an intellectual community. As part of the undergraduate preparation of mathematics majors, we should strive to have them function as mathematicians. The curriculum provides the basic knowledge but there is more to the mathematical education of these students than just that. Departments and universities have large teaching missions and departments should investigate how this mission can provide opportunities for the mathematics majors to communicate mathematics to others, hopefully in some paid position.

Opportunities for carrying out research projects with faculty can be very motivating for students. However, this nation has a thriving research agenda and there are many opportunities for students to carry out research in non-mathematical areas. Mathematics majors with programming abilities are much sought after in university laboratories as well as in industry.

Building a sense of community in a department, one that encourages communication among the different constituents, and that promotes the goals of the department, can be an effective tool for retaining students in the major

<u>Advising and Career Planning</u>

Though most departments have the course of study for the mathematics major clearly outlined, there is much more that is needed in order for students to be successful. Some departments hire professional advisors to provide assistance to students about curricular matters. This serves to inform students about curricular matters, but may not necessarily provide them information about research or teaching opportunities. A concerted effort to provide career information to students would serve to increase opportunities for mathematics majors.

Recruitment and Retention at the Graduate Level

As is the case at the undergraduate level, the range of opportunities for students with graduate degrees in mathematics has grown in recent years. The conventional PhD program in mathematics prepares students for academic careers that involve research and teaching, but students are increasingly finding employment also in the government and private sectors. As these holders of graduate degrees in mathematics become more and more successful in their careers, the demand for such highly qualified employees will grow. It is imperative that the mathematical community stay ahead of the curve on this, recruiting sufficient numbers of students into our graduate programs, creating those programs in such a way as to promote retention and success, and providing a graduate-level mathematics education that prepares students for nonacademic careers as well as traditional academic ones.

1. The transition from college to graduate school

Many college faculty and students view the undergraduate mathematics major as leading to one of two career paths: high school teacher or graduate school followed by a faculty position. This is a stereotype that must be changed if we are to increase the desirability of graduate study in mathematics to a larger number of students. As mentioned above, this change in attitude should start early, with a campaign to expose high school students and teachers to the wide array of opportunities for holders of undergraduate degrees in mathematics. This campaign must be extended to college and university faculty, and include the opportunities available to holders of graduate degrees in mathematics.

Although REU programs provide wonderful summer opportunities for students pursuing undergraduate degrees and graduate students are typically entrenched in their studies and their research throughout the summers, there is a relative lack of summer opportunities for students who have graduated college and are on their way to graduate school. Some graduate programs provide opportunities for their own incoming students, but there are only a few programs that provide opportunities for students in this in-between time on a national level. Such national programs not only provide an enrichment experience that better positions students for success in their chosen graduate programs, they also provide an opportunity for students to become part of the national community of mathematicians beyond the boundaries of their own graduate programs.

The first two years of graduate study are crucial in terms of retention, as most students who stay for a third year tend to leave with a PhD. It is important that departments focus on providing high quality instruction in their entry-level graduate courses as well as sufficient mentoring to students at this beginning stage of graduate study. This mentoring will typically have a different flavor than that provided by PhD advisors, but can continue throughout the student's graduate career. Some graduate programs have formalized this structure, with each PhD student having two distinct faculty advisors: the traditional dissertation advisor who provides guidance as the student develops his or her research program and skills, and a second mentor who helps the student navigate the early semesters of coursework, the demands of being an instructor of mathematics, and the challenges of finding the right post-graduate school mathematical career. By separating these two roles, programs provide a structure whereby students have multiple faculty members whom they can approach with questions.

2. The structure of the graduate program

As with the undergraduate major, the structure of the graduate program is important. Care must be used in designing the graduate exam system, so that these exams do the necessary job of ensuring students are adequately prepared for research and careers while not also serving as needless barriers to student success. The program should be flexible enough to allow students to take courses in areas complementary to mathematics as appropriate, especially if the student is working in an interdisciplinary field or seeking a nonacademic career. Because so many students do, upon graduation, take positions that require teaching, it is important that sufficient training and professional development opportunities are provided in this aspect of a graduate student's life, just as such opportunities are provided in the research realm.

Conclusion

Technology is ever changing and mathematics is at the core of that change. This should be cause for celebration in the mathematical community. This sense of celebration should permeate the way that we communicate mathematics to others and we should make every effort to have the nation celebrate with us.

PANEL REPORT: Technology & MOOCs

Robert Ghrist and **Deborah Nolan**

The expanding role of technology across STEM fields brings both new opportunities and new challenges. These include the balance between analytic-versus-algorithmic training, the role of data in learning, and novel forms of course delivery like MOOCs and flipped classrooms.

Panel Composition

The following panel participants contributed (with the authors) to the discussion:

1. John Bailer, Mathematics, Miami University, OH.
2. Keith Devlin, Professor, Mathematics, Stanford University. Prof. Devlin created the first Mathematics MOOC on Coursera on "*Mathematical Thinking*" in Fall 2012.
3. Jim Fowler, Lecturer, Mathematics, Ohio State University. Dr. Fowler led the popular MOOC "*Calculus 1*" on Coursera in Spring 2013.
4. Diane Lambert, Research Scientist, Google, NY.
5. Steven Sain, Section Head, Geophysical Statistics Project, National Center for Atmospheric Research, Boulder CO.

On Technology

The panel discussed the following questions. How should we prepare students for the expanding role of technology and its uses across STEM fields? Where is there room for improvement? Responses and recommendations are as follow, edited and organized into themes.

I. Key obstacles to overcome with respect to technology and its uses across STEM fields:

Faculty skills:

- The majority of faculty are not trained in the current technologies.
- Many departments have faculty who have buried their heads in the sand when it comes to using technology in the classroom. While they take advantage of markup languages such as TeX and LaTeX, they are still unsure if they should let students use calculators in their classrooms. Instead of looking for the best ways to make use of this technology, they continue to deny its existence and improvement. Soon, they will be so far from the reality of the business world, that they will be expendable. We do not want our math departments to be considered expendable. We need to have time and find ways to incorporate the newer technology into our classrooms at all levels
- Even well intentioned faculty do not have the time to explore technology and spend enough time with the technology to obtain a modicum of expertise, let alone enough to feel confident to implement it. The NSF has supported professional development workshops for K-12 faculty.

Perhaps what is needed now is professional development workshops for college faculty on the use of technology.

Available Materials:

- Many faculty do not have ready access to real-world examples that require modern technology useable in their classes, e.g., problems requiring working with big data.
- No matter how much technology evolves, there is still the aspect that without quality materials, theory and examples, we can get lost in just the technology. Also, keep in mind that these opportunities are very wide-ranging and not necessarily available at all institutions.

Technology Available to Students:

- Students' access to technology for cloud computing or storage of big data is limited. Also, their personal computers often do not have the capacity to handle the demands of medium-sized big data.
- Student Preparation: Students entering the workforce are often overwhelmed at the size and complexity of the data. They need to gain some experience with the complexities that arise in this environment. This includes a general knowledge of programming, how to accomplish things in the computing environment, and exposure to high-performance computing.

II. Emerging best practices with respect to technology and its uses across STEM fields:

Models:

- Computing classes for statistics students: there is evolving definition of statistical computing that aligns more closely with data science. New courses are being developed to teach computer science within a data framework at several institutions, including UC Berkeley, UC Davis, Utah State, St. Olaf, Smith College, and Cal Poly SLO.
- The lecture format for learning about technology is not serving us well. An exploration of active-learning techniques may be in order (see section on MOOCs/flipping below).
- Simply learning how to use a language is not adequate. For example, students need to appreciate *R*. Statisticians at Yahoo, LinkedIn, Facebook, and Google all use *R*. They do not simply treat *R* as a set of functions. Instead, they use it as a medium for transferring results in production. They need to understand the structure of the language.

Programming Skills:

- We need to adopt a broader view of programming for conducting research/data analysis/etc.
- It has been observed that much of the technical training has been focused on code recipes. This kind of training is not sufficient. Technical skills must be more rigorous, i.e., students must be able to create coding solutions that reflect understanding of the data and models.
- Good programming skills are essential. Team-work is more and more important in industry and in academia. Code gets shared on the team as a means of communication. Writing good code is like

good writing. We learn how to program well by looking at lots of code and having our code reviewed by other people. Having people follow a style guide just as they would in writing a report is also helpful.

- More emphasis is needed on real programming and algorithmic skills, rather than just using packages to facilitate learning.
- Most students don't really learn how to write programs at the undergraduate level. All STEM majors should be required to learn how to write basic programs. Students are typically taught to how to run a GUI application rather than developing and implementing algorithms.

Additional Factors:

- We need to massively rethink our core curriculum, particularly at the lower-division level. We need to introduce linear algebra and discrete mathematics at early stages for many students. We need more computation.
- Practical experience obtained by, for example, internship opportunities, where computational thinking and tools are actually used to solve real-world problems is important. This can be even achieved within ones institution if one is involved in interdisciplinary work.
- We need coordination across many analytics fields (including Mathematics, CS, Statistics, and many others that are not obvious such as Library Science)
- Not all the training in technology has to come from statistics/mathematics departments. Better cooperation between Computer Science and Statistics/Mathematics departments is needed.
- We should strive to get students involved in real-world projects, beyond the “homework” mantra of math departments. To accomplish this, we need to encourage collaboration across departments.

III. Unanswered questions with respect to technology and its uses across STEM fields:

- How should we teach mathematical sciences in this new environment? The typical course may be inappropriate for many reasons: lack of local expertise; need for expertise in smaller, disjointed areas;
- How do we best to use statistical tools in high-performance computing environments?
- More and more students enter the university with AP training. How can we build on that background and introduce them to modeling sooner?
- Technology changes quickly so how do we instill in our students the ability to think computationally so that they can stay current, know how to learn about new technology, collaborate work with others?
- An important consideration is what are the learning outcomes that we want to have? Once these are identified then we may be better able to address how we make it happen.

IV. Additional comments with respect to technology and its uses across STEM fields:

- It is important to keep our sights on the core topic, i.e., to understand at a deep internal level data, models, and uncertainty. The ability to think about uncertainty in unusual situations is critical.

- One course in technology is not adequate for students. Students need an early basic preparation in technology, and then technology solutions need to be integrated and incorporated throughout the curriculum, e.g., greater use of simulation in courses.
- Specific technology should not be a focus in math courses. Technology is changing constantly and today's technological aids may be as outdated as Pascal programming by the time the students establish careers. Students should be comfortable using technology and should see its utility in solving concrete math problems. They should also learn the mathematics underlying the technology to increase their ability to use it well.
- The National Academy is about to publish a report titled "*Frontiers in Massive Data Analysis,"* written by the Committee on the Analysis of Massive Data, the Committee on Applied and Theoretical Statistics, and the Board of Mathematical Sciences and Their Applications. It addresses many of the issues facing – A quote from the draft:
  "Statistical rigor is necessary to justify the inferential leap from data to knowledge, and many difficulties arise in attempting to bring statistical principles to bear on massive data. Overlooking this foundation may yield results that are, at best, not useful, or harmful at worst. In any discussion of massive data and inference, it is essential to be aware that it is quite possible to turn data into something resembling knowledge when actually it is not. Moreover, it can be quite difficult to know that this has happened."
- Hal Varian, Google, describes how data are free and ubiquitous and this means the knowledge of statistics is essential as more people want and need to make data-driven decisions at all levels and in many fields.
- We remain too textbook driven. Those who are interested in alternative dissemination practices are the colleagues we meet at workshops in which there is a lot of preaching to the choir going on. It does not broaden the base of people using alternative, effective practices.
- The biggest barrier to adopting widespread changes in teaching is time.
- Have the developers of teaching materials mentor the teachers in an area for all to call upon gratis. Extend the concept of mentoring into a career mentor (coach) on teaching.

On MOOCs

MOOCs, or Massive Open Online Courses, are a recent manifestation of the development of on-line and open-access education. MOOCs evolved from earlier examples of on-line access focused on lecture video libraries (e.g., MIT's *OpenCourseWare*) and short video-lectures with assessments (e.g., Khan Academy). They are characterized by a fuller course experience, including synchronous scheduling (everyone takes the course together) and collaboration through discussion boards. There are at present several MOOC providers, including *Coursera*, *EdX*, and *Udacity*, each with in excess of a million registered participants from around the world.

Though the first MOOCs were in Computer Science and STEM courses, they have quickly spread to nearly all disciplines, including the humanities and social sciences. There are, however, several aspects of MOOCs which are unique to the mathematical sciences.

- Assessments can be easily structured for auto-grading, since we have "ground truth". Even in instances where it is desired to check student work (such as proofs), it is conceivable that regular-expression-checking software will soon evolve to the point where auto-grading is possible here as well.

- The mathematical sciences are inherently modular, incremental, and hierarchical: all these properties make short, focused videos possible and useable for structured learning.
- Mathematical learning has both algebraic and geometric components. Both are amenable to visual learning styles. The use of video makes the full breadth of visual learning possible to a degree unimaginable with a chalkboard or even slides.

In parallel with the development of MOOCs, there is significant interest in “flipping” or “blended” classrooms, in which video-based lecture content is assigned outside of class, reserving class time for working through projects, perhaps in groups, with more personalized attention given. The video-lecture component of MOOCs is well-suited to the current experiments with flipped classrooms.

On MOOCs, the panel offered the following insights:

- MOOCs strike a balance between local engagement (using MOOCs to augment existing university courses) and global outreach (providing access to students who would otherwise be excluded from participation). Both are admirable goals, worthy of pursuit in tandem.
- MOOCs put us in a unique position to demonstrate the beauty behind the Mathematics that we teach. Poor teaching that elevates technique over principles has led to a fundamental public misunderstanding of what Mathematics is and does. The present visibility of MOOCs provides a unique opportunity to change this perception.
- There is much more to MOOCs than video-taped lectures. Most of the existing MOOCs in Mathematics have texts that are paired to the course, discussion forums, meetups, and more to help foster learning and cohesion.
- To this end, it is perhaps best to view MOOCs as an environment for learning more than as a tool for teaching. The focus should be on the student and how the environment can work best for the student (as opposed to how things work for the professor).
- MOOCs provide an opportunity for collaborative teaching, as instructors can work together to build and improve on-line lectures, texts, and assessment activities.
- On a related note, MOOCs are part of a broader movement towards collaborative activities in Mathematics, which includes *MathOverflow* (the forum for asking and answering research questions).
- Development of graduate-level MOOCs in the mathematical sciences would open up access of these subjects to students at smaller schools which cannot field courses in all subjects. Such development would have significant impact in training and should be encouraged.
- One of the most promising features of MOOCs is the adoption of social-network-software features, including gamification and credentialing.
- One challenge is how to chain together MOOCs generated by different professors at different schools. This is not unique to MOOCS – it happens at physical universities too – but it is perhaps more difficult to solve in a distributed manner.

- It seems clear that the data which comes from MOOCs will allow us to greatly improve student learning and performance. We should be planning now for which types of data will best assist assessment and improvement.
- Completion rates for MOOCs are a canard, as what matters is how much net material has been learned, not how many people cross the threshold at the end. In many instances, students who are simply curious about a subject can come away with a great deal of exposure and enthusiasm with just a few weeks of engagement with a course.
- MOOCs are wonderful for people who have already learned how to learn. One big danger is that MOOCs will be seen as a panacea for challenges in primary/secondary schools, where students need personal contact to learn-how-to-learn.
- If mathematicians do not rise to the situation and produce high-quality, challenging on-line mathematics courses, then people (or publishers) who are not mathematicians will produce mathematics courses. If the history of calculus texts repeats itself, a failure-to-engage will lead to low-quality courses aimed at the lowest common denominator with minimal connection to contemporary research.

Theme Report
Fostering Internships for Students at All Levels

by
Angela Shiflet and Bob Starbuck

Promotion of internships should be a major component of workforce development for the next generation of mathematics and statistics graduates. Reasons for this recommendation include:

- Graduate schools often require that those who they accept have research experience.
- Most fellowships opportunities are only available to those with research in their backgrounds.
- Employers are more likely to hire graduates that have had internships in their or other organizations.
- Graduates who have had internships are usually more confident in their abilities, knowledgeable about expectations, and experienced in the profession.

Participants in the online panel came from a variety of backgrounds and brought a variety of experiences to the discussion:

- Tom Gerig, Professor of Statistics at NC State University, was co-founder of the Graduate Industrial Trainee program, which involves NC State and numerous industry partners.
- MathhiasGobbert, Professor of Mathematics at the University of Maryland, is co-PrincipalInvestigator for an “Interdisciplinary Program in High Performance Computing,” an NSF Research Experiences for Undergraduates.
- Amanda Marvelle, Biology Instructor and Director of Digital Media Learning at the Research Triangle High School (TRHS), helped foundthis STEM charter school, which enablesResearch Triangle Park industry internships and projects for its students. Before obtaining her Ph.D. in Genetics and Molecular Biology, she had a variety of internships.
- Debbie McCoy is recently retired from Oak Ridge National Laboratory, where she was Director of the Research Alliance in Math and Science (RAMS) Program for underrepresented students (African American, Hispanic American, Native American, and female American).
- Frank Seelos, Planetary scientist at Johns Hopkins Applied Physics Laboratory, had internships as an undergraduate and helps students with their internships.
- Wei Shen,Senior Director, Global Statistical Sciences at Eli Lilly and Company, is in charge of internships for statisticians.
- Angela Shiflet (co-lead), Larry H. McCalla Professor of Mathematics and Computer Science at Wofford College, for eleven summers participated in faculty research experiences at various government laboratories. The Emphasis in Computational Science, which she was instrumental in

establishing, requires a summer internship involving computation in the sciences.

- Bob Starbuck (co-lead), Assistant Vice President for Special Projects at Wyeth Research (retired), is a statistician with 32 years in the pharmaceutical industry and has helped numerous students with internships.

Value of Internships

Panelists enumerated a long list of “What things were particularly good about your experiences?”

- Opportunity to participate in a “real world” project and gain experience with real day-to-day research.
- Better able to make career choice.
- Multidisciplinary teamwork experience that is so important in science.
- Led to NSF or other fellowship.
- Led to a job offer at the company/laboratory after graduation.
- A bridge to industry.
- Seeing all the different facets of a company.
- A real confidence builder to be able to tackle something with which there was no previous experience.
- Honing skills.
- Networking with many professionals who can give great advice.
- Experience with professional written communication, such as application, resume, abstract, poster, paper, and proposal.
- Enhanced the work of the organization.
- Experience with professional communication with others.
- Experience giving professional presentations at conference or school afterwards.
- Working at an industry site.
- Enhanced resumé.
- Project expanded into Ph.D. research.
- Traveled to another part of the country/world.
- Social activities involving students with similar interests from around the country or world.
- As an employee of the university, ability to work as a foreign student intern in industry (could not do this as an industry employee due to visa restrictions)
- Learning to work in an environment with deadlines.
- Opportunity to use coursework in applied setting.
- Publishing work with company professionals.

Improving Internship Experience

The group also elaborated on “How would you improve upon your experiences?” or “What went wrong?”

- Have staffing in place before committing to an internship program.
- In individual internships, being the only student with no one with whom to interact
- The logistics of finding housing for internships not within commuting distance of the academic campus. Providing support for local housing is very helpful.
- A dedicated mentor should be assigned to each intern and be available to the intern.
- The mentor should reassure the student before hand. Students are usually panicked about know knowing everything and need to hear that they do not need to know everything, just be willing to ask questions. It is much better to ask a question and find out what to do quickly than to accomplish nothing, suffering in silence for a week. (Of course, the student should make an honest attempt to figure it out or “Google” it first and should not be a pest.)
- Sometimes a mentorwas not available or not helpful. Have a backup mentor in mind in case the assigned mentor does not work out.
- Well-defined project not identified in advance.
- Lack of guidance; need regular communication with intern.
- Personality differences. For this issue, panelists stated that students should be prepared to ask for help from a director if things not going well. Informal interactive experiences, such as brown-bag lunches, provide opportunities for students to exchange ideas and experiences.
- Studentswere taken from their projects to help meet anorganization deadline.
- Equipment for the student was not arranged before starting the internship.
- Needed better upfront knowledge of what the internship involved.
- Needed discussion of how student's knowledge and education would be utilized.
- Student was not trusted to do anything more than menial work.
- Difficulty of separating student's desire for pay from need for meaningful collaboration on practical use of academic subject matter.
- Regular communication of academic department with interns and company mentors of interns.
- Should emphasize the need for honest feedback from intern regarding whether the internship is going well and get that feedback periodically so that remedial action can be taken promptly if needed.

Establishing & Maintaining Internships

Internships have been successfully conducted with students ranging from high school through Ph. D. programs.Internship programs vary from summer (typically

12 weeks in duration) to yearlonginternships, where a student works at a local industry site for two days a week and does coursework for the rest of the week.

A key to placing students successfully into internships is making contacts with industry personnel. A good place to make such contacts is at conferences and professional society meetings. If onehears an interesting presentation, meet with the speaker following the talk, tell the speaker about your academic program, and give the speaker your professional card, and get the speaker's card. Later, the faculty member can email the speaker telling about a particular student, including the student's resumé, and inquiring about the possibility of an internship.

One faculty member at West Chester University has successfully used LinkedIn to manage contacts. She created a LinkedIn group "Friends of West Chester University Actuarial Science and Mathematical Finance." She has current students, alumni, and anyone who previously worked with their students join. They may post to the group about internship or even job opportunities, or at least they email her when one arises because the visibility of the group reminds them. She has also had recruiters join the group as well. It has been a win-win situation!

When internship search time comes around, try to match students with industrycontacts. Write the industry contact, telling about the student and attaching the student'sresumé.

Another approach is to look on university websites for professors who are active in research. The student or advisorcan email the professor, telling about the student, attaching a resumé, and asking if the professor has or knows of someone who has an intern position. Frequently, active researchers have NSF money and can apply for supplemental funds for an intern.

Maintaining a steady supply of studentsqualified to participate as interns is advised. That enables a continuing internship relationship between the academic institution and the industrial organization.

Please be aware that export controls (and associated sanctions) can impact research, especially when there is some form of proprietary or security restrictions impacting the open publication of or access to research results by foreign nationals. Be sure to understand institutional policies and the responsible offices for compliance so that a violation of export control laws does not occur when arranging internships for foreign national students; civil and criminal penalties for violating these laws can be significant and personal.

A flexible curriculum helps to enable internships to occur in non-summer months or longer (e.g., 6-month) internships. These less traditional internships may be more attractive to industry, especially the longer versions, since the first month or two of an internship may be consumed by learning the systems and people.

One of the “must haves” for mathematics and statistics student interns is computational skill using a software package. Some industries utilize standard software; e.g., in the pharmaceutical industry, SAS is a standard. A student seeking an internship in a particular industrial setting should be informed or become aware of the preferred software packages utilized in that setting and acquire some proficiency in that software package. This skill is easier to accomplish if the academic curriculum requires computer science coursework, since learning one computer language facilitates learning another computer language. The sooner students acquire this skill, the sooner they become eligible for internships.

Finally, students who participate in internships in high school are typically better prepared to participate in internships while in college.

JOB PLACEMENT

current best practices for connecting mathematical and statistical sciences students to jobs in all sectors

Even as we hear and say that a more technically trained and mathematically and statistically savvy workforce is essential to solve the complex social and scientific problems of today, we still hear just as often the questions "where do math majors get jobs?" or "what can I do with a math major?" It is critical that we increase awareness on the part of university faculty, administration and staff, and students as to the employment opportunities for mathematics and statistics majors. It is certainly well understood that mathematics majors can become teachers or, after a PhD, go into academia but it is essential to know more about what is the real need in the non-academic world for such graduates, what mathematical scientists in industry do, and how can universities better prepare students to be ready to enter into business, industry, and government positions to meet those needs and to face the challenges. This report is to serve as a starting point for further discussion on the theme of "Job Placement" which has the ultimate goal of coming up with best practices for connecting mathematics and statistics majors to jobs in all sectors. We consider **questionnaire** responses from 36 respondents to the Jobs Theme questions: 29 faculty, 2 students who hold Master's degrees, 3 industry, 1 consultant, and 1 unemployed. We also rely on the information garnered in our **live panel discussion** of Thursday 9th May, 2013 which can be viewed at https://www.youtube.com/watch?v=nMXboqa6vbw , and the online discussion that followed. The panel moderators were Dr. Aarti Shah and Prof. Suzanne Weekes, and the panelists were

- Prof. Michael Dorff, Professor of Mathematics & Director of the Center for Undergraduate Research in Mathematics, Brigham Young University;
- Dr. Navah Langmeyer, National Security Agency;
- Dr. Stacy Lindborg, Senior Director, Biostatistics at Biogen Idec;
- Dr. Aarti Shah, Vice President, Biometrics & Advanced Analytics at Eli Lilly & Company,

with offline contributions from

- Dr. Brenda Dietrich, IBM Fellow, Vice President & CTO for Business Analytics, Software Group at IBM.

We also consider input from a number of colleagues in industry who were not formally part of the current project but have had longstanding relationships with the theme leaders.

There are a number of resources that are designed to give examples of the sorts of industries **where mathematicians and statisticians work**. The professional societies have links to such lists. We name here, without any attempt whatsoever to be exhaustive but only to give a sampling, some examples of the fields in which mathematics and statistics students find employment: *actuarial sciences, aerospace engineering, biostatistics, computational biology, computer graphics, cryptanalysis, cryptography, cyber security, data sciences/data analytics, defense, economics, engineering, finance, forecasting, gaming, government agencies, government laboratories, image analysis, information technology, intelligence, law, market research, network design and management, new product development, optimization, pharmaceuticals, programmer, research and development firms, risk analysis, software development, supply chain management.*

It must be emphasized that the prospective job advertisement for which a math/stat major is quite qualified may not say explicitly "mathematician/statistician wanted". Position descriptions may contain phrases such as "problem solving skills", "can pay attention to detail", "can innovate", or "analytical skills". Students must take the initiative to go out and hunt for jobs, sell themselves, knowing that they are bright and qualified. It is very important to build a **network** and keep it active since many jobs still are communicated by word of mouth. On-campus career fairs, job fairs at conferences, AMSTAT News, mathjobs.org, LinkedIn, icrunchdata.com, government labs and agencies websites, are some examples of places where people have been successful in finding job postings.

One does not get the sense from employers that mathematics and statistics students are not technically prepared; it appears that the basic mathematics and statistics preparation that our students receive is for the most part sound. It is recommended that students take some computer **programming** courses and get experience with **software** most prevalent in their field, e.g. R, SAS, Matlab, etc. In industry, it can be crucial to contracts or project timelines to be able to pick out the correct software to use and understand how to transition pieces of a project between software so computer competency is a plus.

To make our students even better prepared for the workforce, however, we must make sure that they are aware of the **soft skills** that are important to prospective employers, and we need to make sure that we provide opportunities during their university career to develop and improve these non-technical skills. Employers value the ability to solve real-world problems, good communication skills, flexibility of thought, initiative and passion, willingness to work on different types of problems, ability to work with a team of people of different backgrounds, and some level of business acumen.

The Reality of the Business: It is helpful if students have a firm appreciation for the difference between textbook applied mathematics and statistics problems and real, industrial problems to which they must apply mathematics and statistics. Industrial problems are not as clean and well-defined as basic research problems usual are; they are often multidisciplinary, quite complex and have conflicting objectives. Data may be large, unstructured, or incomplete. There is often the need for a practical solution that fits within the timeline of a larger project thus requiring that one arrives at a "good", improved solution which is not necessarily a proven, thoroughly analyzed, "best" solution.

Flexibility, Openness, Agility. Quite opposite to doing academic research work, a mathematical scientist considering going into industry cannot have the mindset that "I studied X at school and I want to keep doing X." In industry, depth in one field is good, and even essential for some industries, but one needs to be open to different sorts of problems requiring different analytical tools. A degree in mathematics or statistics indicates that a candidate has some analytical ability and enjoys solving problems, so an employer will want that his/her employee is interested and open to listening to, understanding, and working on different types of problems that arise in the business. Over time, the breadth of knowledge and experience that such an employee possesses allows him/her to become more agile and more valuable.

Initiative & Passion. Valued industrial mathematical scientists must not be passive in that they must actively participate in discussions and be able to see themselves what statistical or mathematical problems need to be investigated in order to move projects forward and to benefit the business. They must not simply wait for such problems to be assigned. They must be able to understand the challenges a business faces and be able to help solve those challenges. Employers need to be able to see some indication of initiative and passion from a prospective employee and one way that employers see this is when the candidate can speak about a focused research experience that he/she has had.

The Three C's - Communication, Collaboration, Communication. Yes, we know that we said "communication" twice. That is because it is the word that appears most frequently in our discussions with people in industry.

Work in industry does not occur in silos and, often, mathematicians and statisticians must work with colleagues who are not trained as mathematical scientists. Thus, it is helpful if a prospective employee can point to experiences that will lead one to infer that he/she can collaborate successfully on teams that are diverse in terms of core disciplines and, of course, diverse in terms of personalities and backgrounds. Mathematicians and statisticians in industry invariably are often in the position where they must communicate their ideas and their results to non-technical people. It is important to be able to explain to one's teammates why they should pursue your approach and, sometimes, one is in a position of having to do so without explaining exactly what the mathematics is. Ideas must be eventually presented to management in an effective way so that decisions regarding money or time investment, product development, or strategy shifts can be made. To drive the communication point home in an accessible way, data analysts use the term 'storytelling' - one must be able to tell the story that is written in the data and present it so that everyone understands the insights and so that one can return to the data with new questions. The bottom line is that one's work is useless if no one else can understand it enough to make decisions based on it.

SUGGESTED PRACTICES

Build stronger university-industry connections. It is beneficial for universities to have active connections with business, industry and government to get insight into what are the sort of problems that are of interest, to understand what are the different industrial cultures, to get better perspectives on the technical and non-technical expertise that is of value outside academia, and of course to build employment pathways for their graduates. Industry benefits by getting the opportunity to tap into developing talent and they can use these relationships for recruitment purposes.

We suggest thinking of creative ways to build those academia-industry relationships and to provide students with real-world motivated problems. Some examples of partnerships include:

- Industrial research projects for students; collaborative projects;

- Using real industrial data for student problems, i.e. messy, incomplete data;

- Having industry representatives on PhD committees;

- Faculty sabbaticals in industry.

Build Network. Maintaining an alumni database and remaining actively in touch with department alumni is very helpful. Alumni have already a connection to their major department and should form the backbone of the department's network with the outside world. Alumni can be invited to the department to meet with the students and the faculty. It is important to know:

- What jobs are alumni finding?
- What courses were helpful in preparation for their career?
- What do they wish they had exposure to while they were in school?
- What do they like/not like about their job?
- What advice, in general, would you give to current students to help them be successful in their careers?
- What are internship opportunities?

Faculty should attend the Career Fairs on campus and meet with company representatives.

Increase students' exposure to other disciplines. It is recommended that students take courses outside of mathematics and statistics and develop some basic level of comfort with disciplines such as behavioral economics, marketing, psychology, logistics. It is also recommended that students take 2 or 3 business courses, if possible, to help them develop greater business literacy and business appreciation.

Develop Communication and Presentation Skills. It is important that mathematical scientists can communicate effectively in writing and orally. Mathematical scientists in industry must be able to communicate their technical ideas to non-technical people and need to help others understand why their idea is worth pursuing without going into technical details. Students can improve communication skills in a number of ways:

- Taking writing intensive courses;
- Presenting their research or work from existing papers orally using PowerPoint, Beamer, etc.;
- Giving poster presentations – students must be able to engage audience with a 1-2 minute overview, and should also

be able to give more details in a 10-minute presentation. Many math and statistics conferences have undergraduate poster sessions. It is also recommended that students present their work at multidisciplinary conferences such as those run by the Council on Undergraduate Research; this forces students to figure out how to explain their work to non-mathematicians.

- Listening to and studying examples of excellent talks, such as TED talks;
- Receiving feedback on their communication; may seek out feedback from someone in the field, as well as non-technically trained friends or family members.
- Participating in an organization such as Toastmasters.

Intense Learning Experiences. It has proven very beneficial for students to have worked on projects outside of the traditional assignment mode. They should get the experience of working on an open-ended project where the result is not known a priori. Such experiences can be gained via internships, research projects on campus, or from focused research experiences such as the NSF Research Experience for Undergraduates (REU) programs. We hold that engaging in research will make students better at problem solving, critical thinking, independent thinking, creativity, and will enhance their intellectual curiosity, disciplinary excitement, and communication skills. The particular experience that they get from working on such projects provides a source that can be drawn from to demonstrate that they have some of the hard and soft skills that were discussed in the first part of this white paper.

INGenIOuS Measurement and Evaluation

Peter R. Turner[1], William M.K. Trochim[2], David P. Wick[3]

Introduction

The purpose of this white paper on the Measurement and Evaluation theme of the INGenIOuS project is to set the stage for discussions at the program workshop in July 2013. The overarching goal of the project is to develop strategies to help train and enhance the mathematics and statistics workforce at the undergraduate and graduate levels. The acronym INGenIOuS stands for Investing in the Next Generation through Innovative and Outstanding Strategies.

The overall project has six themes: Recruitment and Retention, Technology and MOOCs (Massively Open Online Courses), Job Placement, Internships, and Documentation and Dissemination, in addition to Measurement and Evaluation. It is apparent that all of these interact extensively and that they reach beyond disciplinary programs in mathematics and statistics themselves.

Much of the remainder of this white paper is formulated as a set of annotated questions. These questions and their contextual answers will potentially provide a basis for the design and evaluation of future projects and programs which aim to enhance training of mathematics and statistics students at the undergraduate and graduate levels.

Who are the Stakeholders?

1. Certainly primary stakeholders in any project addressing mathematics and statistics education at college levels (graduate *and* undergraduate) are the Universities and Departments themselves. This includes several groups whose interests are related but not necessarily fully aligned:
    a. The undergraduate and graduate students
    b. The teaching and research faculty
    c. College and University administrators

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2. The workforce development objectives certainly imply that employers (industry, academia, government, NGOs) are important stakeholders.
3. Planning of workforce development brings in government and government agencies including
    a. Bureau of Labor Statistics
    b. Office of Science and Technology Policy
    c. National Science Foundation, and other research agencies/departments
    d. Federal and State Departments of Education

4. The Recruitment and Retention theme introduces an additional set of stakeholders including
    a. Education researchers and mathematical scientists with interests in education
    b. Under-represented groups and advocates/ strategists in developing diversity in the STEM pipeline
    c. The K-12 educational community
5. The technology theme brings in
    a. Developers of educational technology
    b. MOOC providers and developers
    c. Publishers
    d. University administration
6. Documentation and dissemination impacts almost all of the above and the Professional Societies with their interests in
    a. Supporting the mathematical sciences professions
    b. The future membership pipelines
    c. Educational programs
    d. Publishing – research and educational materials

Why is this project important?

STEM professionals change lives by, among other things, engineering better medicines, bringing clean water solutions to remote regions of the world, and building a sustainable energy future for the sake of the planet. In all of these endeavors, the central role of mathematics and statistics cannot be underestimated. There is broad consensus that sustaining US competitiveness in an increasingly global environment depends on the quality and supply of the STEM workforce [1]. The science and engineering labor force makes up roughly 5% of the nation's total workforce, yet over the last 50 years it has been responsible for 50% of the country's sustained economic growth [2].

According to the 2010 PCAST (President's Council of Advisors on Science and Technology) report, Prepare and Inspire: K-12 Science, Technology, Engineering, and Math (STEM) Education for America's Future, 60% of students entering college as STEM majors, switch out [3]. Many students never make it into the STEM pipeline because of inadequate preparation in math and science. Many students who are qualified don't choose STEM majors. Furthermore, as we work toward addressing pedagogical and attitudinal changes for improving the STEM pipeline, we need to build a framework for defining competencies and skills for a 21st century STEM workforce.

These realities convey both the opportunities and challenges in the nation's quest to improve the size and composition of the STEM workforce. In the 2012 PCAST report, Engage to Excel, the President's council calls for one million additional college graduates with degrees in STEM [4]. In this matter of national interest, the President is calling universities and institutions to action, imploring special programs and centers to lead, and calling for the next generation of STEM professionals to be part of the solution.

What national-level background is relevant to diversity issues?

Many potential sources of STEM workers remain untapped. We need to do a better job of recruiting a greater proportion of students from demographics that are traditionally underrepresented in STEM.

At only 26% (in 2008) of the total science and engineering workforce, women remain largely underrepresented, although to a lesser degree than previously (21% in 1993). Women are much better represented in the social, biological, and medical sciences at 50%. However, only 13% of engineers are women and only 26% are represented in the areas of computational and mathematical sciences [5].

Race and ethnicity also play a role. While African American, Latino American, and Native Americans make up roughly 26% of the general population, they represent only 9% of the science and engineering workforce [5]. Further emphasizing the disproportionate representation is the US Census Bureau's projection that the groups traditionally referred to as the underrepresented minorities collectively become the majority by 2050, largely due to the projected expansion of the Latino population [6].

The work of groups such as the National Action Council for Minorities in Engineering (NACME), National Society of Black Engineers (NSBE), the Society of Hispanic Professional Engineers (SHPE), American Indian Science and Engineering Society (AISES), among others, is predicated on the belief that the best science and engineering team is one that "looks like America" – one that values diversity and is in tune with the needs and future direction of the country.

What is a Program Model?

This extensive group of stakeholders will likely have differing perspectives on what outcomes any particular project should focus on and how we might achieve those outcomes. Because of this, it is critically important to engage the stakeholders in articulating a model of a program that most if not all stakeholders can buy into, and that can guide the evaluation. Evaluation has a long history of using program logic models and causal pathway models (theory of change) [7-10] to describe the key activities of a program or activity and how these are expected to lead to short, medium and long-term outcomes. Critical early questions in developing such a model would include:

- What do we mean by any given program? What is included in the program (and its model) and what is not?
- What are we trying to do/accomplish with this evaluation?
- How do the stakeholders fit into a broader systems view?
- How can we most effectively express the relationship between activities and outcomes in a model?

What Outcome Measures are likely to be in ***any*** Potential Model?

Evaluation that proceeds without a coherent model tends to result in a smorgasbord of disparate measures that don't relate to the program's strategic objectives or tell an integrative story about the program's effectiveness. That said, while awaiting the development of a comprehensive model it is still possible and potentially useful to anticipate outcomes and measurement approaches that would likely be central in *any* eventual such model.

Certainly, changes to educational programs that aim to impact workforce development will need to be assessed, inter alia, in terms of:

- Attitudinal surveys and trends
- STEM College readiness
    - Surveys of persistence in math and science course sequences
    - Interdependence of math/stat and scientific preparation levels
- The nature of student involvement in their education
    - Early research or discovery-based learning
    - Effects of changes in learning styles, active vs. passive for example
- Impacts of encouraging, or even requiring, internship experience
    - On job placement rates and satisfaction
    - On preparation for graduate schools
    - On awareness of applications fields
- Readiness for math/stat-based careers
    - Critical analytic thinking abilities, and changes in those
    - Ability to *apply* acquired knowledge
    - Retention and advancement in those careers
- Retention effects resulting from changes to early college STEM, especially, mathematics, statistics and computing, course structures and experiences
    - First to second year retention in math/stat, or STEM majors
    - Graduation rates within math/stat/STEM majors
- There is a parallel set of questions to be considered for graduate programs
    - Graduate School readiness

    - Are our BS graduates well prepared for graduate schools?
    - Persistence rates, ability to transfer skills and knowledge to other fields or teams
    - Abilities to communicate mathematical concepts, models and results
- Retention efforts at the graduate level (coursework to dissertation; successful completion of qualifying/comprehensive exams)
- Mentoring at *all* levels, and among different levels
- The effect of technology innovations
    - Widespread use of MOOCs as course supplements, or even replacements
    - Electronic texts offer great flexibility for student learning

The specific research questions related to any of these will depend on the overarching model and the specific context.

What baseline data/information is available or should be collected?

Obviously answering this question fully requires at least some answers to the questions above. However it will be important to gather some baseline data, sooner rather than later, in each of the categories above.

There has been extensive data collection on persistence through the calculus sequence (see the MAA study [13] for example). National data for STEM graduation and retention rates is available – and has been heavily cited in, for example, the PCAST *Engage to Excel* report [4]. That report also has data on future needs for STEM professionals. There are also local studies on attempts to address transition issues, [14-16] for example. The National Center for Educational Statistics, NCES, http://nces.ed.gov/, is an extensive resource for data at all levels of the educational spectrum, including both graduate and undergraduate mathematics and statistics, and application domains. For example, data on proportions of foreign or domestic students earning graduate degrees in mathematical sciences sheds some light on the readiness, retention and attitudes of our BS graduates.

Educational literature has much to offer on the effectiveness of different teaching styles: active vs. passive, problem-based learning, flipped classrooms etc. A good summary for the transitional experience at the intersection of mathematics and the life sciences is [17]. The Physics education literature is extensive and many of the lessons there are likely applicable to math/stat education, too.

Almost all workforce development plans demand critical thinking skills and within the math/ stat/ computation realm that certainly entails analytical skills, too. Bloom’s taxonomy is a commonly cited classification of critical and application of higher order thinking.

However the development of well-structured and progressive curricular content raises the issue of measuring the level and complexity of problems and problem statements. This is a likely research topic that would inform both curriculum, or program, development and the assessment of their implementation.

One important piece of baseline data is perhaps the collection of a good bibliography that draws these somewhat disparate pieces together.

How do we assess longer-term outcomes?

In this section we concentrate on the problems associated with longer term evaluation of projects designed to train the next generation of graduates in the mathematical sciences.   How do we assess sustainability and/or reproducibility? A reasonable objective for the INGenIOuS workshop is therefore to determine some of the key issues and questions to be addressed.

In order to frame those questions an early determination will be necessary to

- Decide about labor force needs “to the right” of the pipeline model.
  The list of stakeholders has many potential “outputs” from the pipeline. In order to focus on key issues, either a set of common requirements should be set, or a set of career paths could be identified. This will help frame the key outcomes to be assessed in the overall structure.

With that in place we can identify the main questions to be addressed in the (future) programs and their evaluation.

There are many approaches to measurement and evaluation of educational initiatives. Studies are often highly detailed and local, or more broadly based in both contexts. Therefore

- What measurements/data should we try to collect?
- How will we determine success or failure for the initiatives?
- How do we combine varying local studies with much common purpose into a meaningful broader-based analysis?
  Meta analysis is one potential approach to this particular issue. Another would be to identify common evaluation questions or outcomes across multiple local projects and aggregate across such commonalities.

This is a classic "systems" problem: at what level ("local" or "global", "part" or "whole") are we going to evaluate? Different stakeholders will have different preferences. For instance, program implementers and those closest to the program action will tend to argue for evaluations that are sensitive to local and unique contextual circumstances. They tend to want evaluations that have practical value for improving their local implementation. Funders and industry stakeholders will tend to be more interested in evaluations that provide aggregate results across multiple local settings. They are typically more interested in global accountability. Most likely some mixture or combination of both will be necessary. A program model is designed to help navigate this potential tension. For instance, local stakeholders tend to be more interested in shorter-term outcomes that provide more immediate feedback that can be used to guide the program. Stakeholders with a global perspective tend to be more interested in longer-term outcomes that can show broader impacts. (See Trochim's "Golden Spike" paper to see how this can be addressed [12]).

However even before attempting to answer these questions for any particular program, we must determine

- What are we trying to do/accomplish with this evaluation?
- How do the stakeholders fit into a broader systems view (e.g., local-global or part-whole)?

Armed with the answers to those, we must determine

- What are the key evaluation questions?
- What are the measures for key outcomes?

At a broader programmatic level, it is then important to consider

- What outcomes/measures are relevant across local models/programs?
- How can we aggregate results across local programs or initiatives to generate a global picture?

How will evaluations be used?

Evaluation can be used for a variety of purposes. It can provide immediate feedback about the functioning of programs. It can be the basis for program variation comparisons and for program improvement. It can be used to make decisions about which programs to retain and which to eliminate. It can be used to "tell the story" of a complex program in a manner that is rich and compelling. In many cases, one will want to do many or all of these. The central problem that results is that there is often a tension among these, and certainly there is the ubiquitous challenge of limited resources for conducting evaluation. Typically, tough choices have to be made regarding where to allocate evaluation efforts. This usually translates into considerations about how to balance the needs and interests of various stakeholders so that everyone feels the evaluation has direct use for them while recognizing the legitimate interests of others. For instance, the more evaluations are used to make program funding decisions the greater the pressure on program managers and advocates to make their results look good. This can lead to problems like "teaching to the test", reluctance to participate in data collection efforts (and consequent low response rates), and even conscious attempts to distort the data. On the other hand, evaluations that only tell the story of the program but do not rigorously assess both the good and bad will be criticized for being biased, unscientific and essentially at the level of marketing materials. This tension related to evaluation utilization is one that needs to be worked out through engagement of various stakeholders and the development of coherent models that show how different results can be used to address different purposes.

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Theme Report

Documentation and Dissemination

Panel Participants:

- Claudia Neuhauser (lead; University of Minnesota Rochester; Vice Chancellor for Academic Affairs and Student Development; Director of Graduate Studies of Biomedical Informatics and Computational Biology)
- P. Gavin LaRose (panelist; University of Michigan; Lecturer IV and Instructional Technology Manager, Department of Mathematics)
- Laura Kubatko (panelist; The Ohio State University; Associate Director at the Mathematical Biosciences Institute; Associate Professor, Department of Statistics and Department of Evolution, Ecology, and Organismal Biology; Chair of the Interdisciplinary Ph.D. program in Biostatistics)

References are collected in the Appendix.

Educational practices in the mathematical sciences in higher education range from traditional lecture to active learning techniques, such as problem-based or inquiry-based learning. These are supported by open-source and commercial curricular materials that range from traditional textbooks to technology-enhanced instructional tools, such as learning management systems or machine-graded homework systems. Commercially available materials are marketed directly to faculty and departments through publishers' sales representatives and other advertising. Open-source materials largely rely on dissemination efforts by individual faculty or professional organizations.

As a result of the many different sources for these curricular materials, the number of sites where resources are available is staggering. The panel reviewed a few of them during the discussion. The available resources complement each other both in content and in their accessibility to different instructors and teaching styles, and thus have their unique niches that balance the diverse needs of users. They include homework problems, inquiry-based modules, tutorials, complete courses, webinars, video lectures, assessment instruments, and workshop materials. (We list some of the resources in the Appendix in no particular order and with no attempt to be comprehensive.) The number and the diversity of resources are needed to meet the needs of the very large community of mathematics and statistics educators and learners, but also pose significant challenges. Included among these are that it becomes difficult to quickly find resources that are suitable for a specific need, and many resources lack appropriate documentation that would allow faculty to evaluate the suitability of the resource quickly or to determine how to use it effectively.

Some of the resources have quickly built a user base, such as Khan Academy or MOOCs, while others linger on websites with little chance of being found. It should be noted that Khan Academy and MOOCs have their primary following among people whose intention is to learn the materials in the first place. Self-motivation is likely a significant factor in their being effective. For all available resources, word-of-mouth and publicity through blogs or newspapers contribute to dissemination success. It appears to be more difficult to duplicate the rapid dissemination success for resources that target instructors (rather than learners).

Face-to-face workshops and longer-lasting communities (such as Project NExT, PKAL, or workshops offered through CAUSEweb) are particularly effective means of dissemination of pre-selected educational practices to a targeted audience but tend to reach smaller numbers of users and require a significant time commitment of the participants, quite often including travel and overnight stays in hotels. However, since the presented materials are carefully selected and the users are actively engaged in face-to-face discussions, it is easier to adopt them later on in the classroom.

Online resources such as WeBWorK or the resource library of CAUSEweb have a much larger user base and often come with support in the form of online forums or access to consultants, but typically require the user to sift through resources to find something that meets their needs. Assessing the suitability of a particular online resource can be very time-consuming, and this often becomes a barrier to adoption due to the many other time-consuming demands on faculty. Furthermore, whether or not a resource works for a given instructor also depends on her or his teaching style and pedagogical approach which contributes to the difficulty of assessing the appropriateness of materials for use by any given instructor.

While not used extensively for dissemination of course materials at this time, webinars appear to strike a balance between face-to-face workshops and online repositories. There are some examples where this is being done effectively, including the MAA's PREP workshops, some of which are entirely on-line. Such webinars allow real-time community engagement without the need to travel and could be a particularly effective way to introduce a more complex module to interested educators or to discuss educational practices. Archived webinars can then serve as the documentation for future users.

The extent of resources available on-line makes a single access point no longer feasible. Instead, resources will be distributed among a very large number of sites, and we will continue to see, and need, diverse means of dissemination. Many of the materials that are shared on the web were first developed by a faculty member for use in their own classroom. What is needed for successful dissemination therefore is often an afterthought, and thus there is a need to raise awareness of the desirability of incorporating documentation and assessment of curricular materials when the materials are developed.

There may be a need to have ways to determine where resource gaps are. These could be identified in panel discussions at workshops. National reports, such as reports by the National Research Council (NRC) and PCAST, may also be helpful to point to anticipated needs. For instance, both Math2025 and a recent PCAST report "Engage to Excel" emphasize the need for high-level trained mathematical scientists to work in a data-intense world. This is a change that occurred only recently with the advent of large data sets, and to prepare students for careers in this data-intensive environment, we will likely need well-documented large data sets. While many large data sets are freely available, it is not easy to find them, and even if found, it is often difficult to adapt them for use in a classroom. Two significant barriers to the dissemination of all resources are (1) the difficulty of finding them in the first place; and (2) the ability to quickly assess their potential usefulness. These are areas on which future efforts should be focused. To find resources, a tagging system could be developed that would allow an expert system to recommend resources to users, similarly to Amazon's "Customers Who Bought This Item Also Bought"; similarly, ways to push materials that have a high probability of usefulness to educators directly may be useful. This would require a way to codify teaching styles and the development of a rating system that would learn from the user. Another idea to identify suitability is to have ways to share teaching experiences, e.g., using blogs where users can explain in free text how they used the resource and what worked and what did not work.

A barrier for improving documentation is the current academic reward system, particularly at research universities. Unless credit is given for developing documentation for teaching resources there is little incentive to do so. The mathematical science community needs to develop a robust peer evaluation system that encourages creators of curricular or assessment materials to polish the work for easier adoption. This needs to be undertaken in parallel to an effort to make this kind of work "valid" academic output that counts toward promotion and tenure. The mathematics community may want to look at AAAS's efforts to highlight educational efforts in their *Science* magazine[1]. High-profile publications of educational efforts, whether new pedagogical approaches, curricular materials, or assessment, could greatly help their dissemination. There are other efforts, such as MERLOT, that provide peer-reviewed materials. MERLOT offers workshops to become a MERLOT Peer Reviewer. Furthermore, it is important to instill in graduate students and beginning faculty the importance of investing time in developing their pedagogical

1 Alberts, B. Reflecting on Goals for *Science*. Editorial. Science 339. 4 January 2013: 10.

skills and to expose them early in their career to the many resources available. Examples of efforts to do this are Preparing Future Faculty and Project NExT.

We identified a critical need to provide assessment resources. A significant barrier to developing good assessment tools is the lack of assessment expertise among faculty in the mathematical sciences. While faculty regularly give exams in mathematics and statistics courses, assessment should happen much more broadly. Examples for assessment instruments that go beyond exams are, for instance, Grinnell College's surveys to measure the effectiveness of undergraduate research.

There may be benefits to developing assessment tools collaboratively, perhaps even at the proposal stage. When faculty groups apply for funding, such as REU funding, they need to include an assessment plan. Instead of each group developing their own plan of assessing similar efforts, we should find ways to collaborate on the assessment. A significant barrier to this is the competitive nature of proposals and the lack of knowledge concerning who else is planning to submit a proposal.

During the discussion, we repeatedly addressed the need to build communities. Workshops are one way to get users together. Communities have also formed around specific pedagogical methods, such as the Moore method. With the development of social networks online, however, there appear to be other ways to connect users. We recognize that online communities are often less efficient since information transfer is asynchronous and thus more time consuming. However, if users shared the resources they are currently using or have used in the recent past, it may be easier to develop temporary communities where users can get together in virtual space to share their experiences.

During our panel, we learned about the planned effort of the Mathematical Biosciences Institute to develop new educational initiatives, including online tutorials prior to workshop activities, extensive online modules, and curricular materials for graduate level instruction. This builds on their past efforts of undergraduate summer programs, graduate summer programs, workshops for young researchers, and teaching-focused summer workshops.

The NSF Mathematical Sciences Institutes play an important role in connecting people within and without the mathematical community. While their primary focus is on fostering research collaborations, many also engage in educational activities, including the maintenance of large video libraries of presentations of advanced mathematical topics that are openly accessible. The NSF Mathematical Sciences Institutes should continue to play a role in fostering communities and expand their role to educational aspects, in particular at the more advanced level where fewer resources are available. The current plans of MBI are a step in the right direction.

We also discussed technical issues: many of the current learning management systems are not "math-friendly." There is thus a need to develop platforms that allow the creation of mathematical content. It is difficult to communicate mathematics online, especially to novice learners. Not being able to easily build equations or produce graphs online is a communication barrier. Tablet technology is becoming a way to annotate figures and graphs on the fly, but this technology is still in an early stage. What is needed is a way to dynamically interact with resources in a user-friendly way and to have visually appealing interfaces.

While much of our discussion focused on teaching resources, we spent some time discussing the need to have communities of faculty that engage in discussions on effective teaching in mathematics. These communities could help characterize teaching styles and what kind of materials work well with what style.

As discussed earlier, a mix of commercial and open-source resources are available. For an individual faculty member who wishes to disseminate their resources, it becomes important to decide early on whether to go the open-source or commercial route. Either one has its advantages and disadvantages. Whether commercial or open-source, only well-supported resource platforms have longevity. In our rapidly changing technological environment, there may be an advantage to partnering with for-profit companies to better stay ahead of the technological curve and to provide a well-established editorial structure that may ensure quality products. As an example, many universities have partnered with Coursera or Udacity to disseminate their courses world-wide. Since such platforms are expensive to create and maintain, it would be inefficient for every university, or perhaps even small consortia of universities, to build their own platform. Conversely, there are arguments for open-source resources: the academy has a history of embracing such resources, especially because of their low cost and specific focus on addressing a well-defined need, and there is a precedent for many commercial products to be based on open-source platforms because they may be the best and cheapest starting point.

As with all intellectual property, any efforts need to clarify ownership of resources.

Appendix: Open-source and commercial resources

The short descriptions are directly from their websites (unless noted otherwise).

- CAUSEweb (https://www.causeweb.org/)
  - "Arising from a strategic initiative of the American Statistical Association, CAUSE is a national organization whose mission is to support and advance undergraduate statistics education, in four target areas: resources, professional development, outreach, and research."
- WeBWorK (http://webwork.maa.org/)
  - "WeBWorK is an open-source online homework system for math and sciences courses. WeBWorK is supported by the MAA and the NSF and comes with a National Problem Library (NPL) of over 20,000 homework problems. Problems in the NPL target most lower division undergraduate math courses and some advanced courses."
- Project NEXT (http://archives.math.utk.edu/projnext/)
  - "*Project NExT* (New Experiences in Teaching) is a professional development program for new or recent Ph.D.s in the mathematical sciences. It addresses all aspects of an academic career: improving the teaching and learning of mathematics, engaging in research and scholarship, and participating in professional activities. It also provides the participants with a network of peers and mentors as they assume these responsibilities. To date, 1400 Fellows have participated in Project NExT."
- WebAssign (commercial) (http://www.webassign.net/)
  - "WebAssign is the leading provider of powerful online instructional tools for faculty and students. In brief, instructors create assignments online within WebAssign and electronically transmit them to their class. Students enter their answers online, and WebAssign automatically grades the assignment and gives students instant feedback on their performance."
- MyMathLab (commercial) (http://www.mymathlab.com/)
  - "MyMathLab is a series of online courses that accompany Pearson's textbooks in mathematics and statistics. Since 2001, MyMathLab--along with MyStatLab and MathXL, have helped over 9 million students succeed at more than 1,900 colleges and universities. MyMathLab

engages students in active learning—it's modular, self-paced, accessible anywhere with Web access, and adaptable to each student's learning style—and instructors can easily customize MyMathLab to better meet their students' needs."

- You Tube (http://www.youtube.com/)
    - "YouTube is a video-sharing website, created by three former PayPal employees in February 2005 and owned by Google since late 2006, on which users can upload, view and share videos. The company is based in San Bruno, California, and uses Adobe Flash Video and HTML5 technology to display a wide variety of user-generated video content, including movie clips, TV clips, and music videos, as well as amateur content such as video blogging, short original videos, and educational videos." (Source: http://en.wikipedia.org/wiki/YouTube)
- Coursera (https://www.coursera.org/)
    - Coursera is an education company that partners with the top universities and organizations in the world to offer courses online for anyone to take, for free. Our technology enables our partners to teach millions of students rather than hundreds.
- Udacity (https://www.udacity.com/)
    - Our mission is to bring accessible, affordable, engaging, and highly effective higher education to the world. We believe that higher education is a basic human right, and we seek to empower our students to advance their education and careers.
- edX (https://www.edx.org/)
    - EdX is a non-profit created by founding partners Harvard and MIT. We're bringing the best of higher education to students around the world. EdX offers MOOCs and interactive online classes in subjects including law, history, science, engineering, business, social sciences, computer science, public health, and artificial intelligence (AI).
- Khan Academy (https://www.khanacademy.org/)
    - "Khan Academy is an organization on a mission. We're a not-for-profit with the goal of changing education for the better by providing a free world-class education for anyone anywhere. All of the site's resources are available to anyone. It doesn't matter if you are a student, teacher, home-schooler, principal, adult returning to the classroom after 20

years, or a friendly alien just trying to get a leg up in earthly biology. Khan Academy's materials and resources are available to you completely free of charge."

- Grinnell College Assessment Instruments (http://www.grinnell.edu/academic/csla/assessment)
    - CURE survey (Classroom Undergraduate Research Experience)
    - RISC survey (Research on the Integrated Science Curriculum)
    - ROLE survey (Research on Learning and Education)
    - SEA CURE survey (Science Education Alliance Classroom Undergraduate Research Experience; a National Genomics Research Initiative)
    - SURE III survey (Survey of Undergraduate Research Experiences)
- PKAL (http://pkal.aacu.org/blog/)
- MERLOT (http://www.merlot.org/merlot/index.htm)
    - MERLOT is a free and open online community of resources designed primarily for faculty, staff and students of higher education from around the world to share their learning materials and pedagogy. MERLOT is a leading edge, user-centered, collection of peer reviewed higher education, online learning materials, catalogued by registered members and a set of faculty development support services. MERLOT's strategic goal is to improve the effectiveness of teaching and learning by increasing the quantity and quality of peer reviewed online learning materials that can be easily incorporated into faculty designed courses.
- Moore method (http://legacyrlmoore.org/index.html)
    - Links to further sites can be found on Wikipedia (http://en.wikipedia.org/wiki/Moore_method)
    - The Academy of Inquiry-based Learning (http://www.inquirybasedlearning.org/)
- Math2025 (http://www.nap.edu/catalog.php?record_id=15269)
- PCAST report (http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf)

APPENDIX C

Workshop schedule

	Monday, July 15	Understanding the Challenges
9:00-11:00	**Welcome & call to action** **Facilitator and participant introductions**	To welcome the participants and clarify the objectives of the INGenIOuS project and the workshop deliverables; To establish a set of ground rules and expectations with respect to the meeting process; To help people meet one another, establish rapport and get to know what knowledge, experience and diversity is present in the room. Also to identify and be aware of what expertise is not present at the workshop.
11:15 – 12:45	**Exploring the six themes**	To extract key questions and challenges from discussions grounded in the six themes (Recruitment & Retention, Internships, Job Placement, Technology and MOOCs, Measurement & Evaluation and Documentation & Dissemination).
1:45	**Organizing challenges**	To organize the challenges generated in the previous activity.
2:45 – 3:45	**Understanding the stakeholders**	To gain a more thorough and granular understanding of the different stakeholders of the INGenIOuS initiative and the role they play.
4:00	**Stakeholder presentations**	To communicate the output of the stakeholder activity to the rest of the workshop participants.
5:00	**Closing**	To debrief the day and set expectations for next steps.
5:30	**Speaker presentation**	Nicole Smith
	Tuesday, July 16	**Exploring Solutions**
9:00	**Initiative inventory**	To collect and organize an inventory of existing projects, initiatives and best practices.
10:30 – 4:00	**Generate options for potential projects (Rounds 1, 2, 3)**	Explore potential projects using the outputs from previous activities as the initial prompts. Share projects and provide preliminary peer feedback.
4:15 – 5:15	**Evaluating the projects (Round 1, 2)**	To divide into subgroups and evaluate the potential projects created in the three previous rounds using a wide range of criteria (Round 1) or using criteria specifically focused on resource requirements (Round 2).
5:15	**Poster session**	To review the evaluation posters generated by the other groups.
5:45	**Closing**	To debrief the day and set expectations for next steps.

	Wednesday, July 17	Looking Forward
9:00 – 12:00	**Implementation matrix**	To synthesize the evaluation posters and prioritize the projects based on overall priority.
1:00	**Funding strategy**	To create an understanding of the reason projects were prioritized and distill the values, goals and objectives that should inform funding strategies.
4:00 – 5:00	**Closing**	To acknowledge the contribution of the participants, address next steps and perform a final debrief of the workshop.

Workshop leaders welcomed participants and clarified objectives of the INGenIOuS project and deliverables of the workshop. Next, participants agreed on ground rules and expectations for the meeting process. Participants introduced themselves, established rapport, and got a sense of the group's knowledge, experience, and diversity—and areas in which such expertise was lacking.

Next the group explored the six pre-workshop themes (Recruitment & Retention, Internships, Job Placement, Technology and MOOCs, Measurement & Evaluation, Documentation & Dissemination), extracting key questions and challenges. Then participants cooperated to organize these challenges. A discussion and report-back built a deeper and more granular understanding of the different stakeholders of the INGenIOuS initiative and the roles they play.

Nicole Smith, from the Georgetown Center on Education and the Workforce, gave an engaging presentation on STEM occupations and how they relate to U.S. economic competitiveness, innovation, economic growth, and productivity (see http://cew.georgetown.edu/stem/).

Day Two began with an activity designed to collect and organize an inventory of existing projects, initiatives, and best practices. Groups of participants were assigned to explore potential projects using the outputs from previous activities, and then to discuss projects with the entire group, offering preliminary feedback.

In the final activity of Day Two, participants formed subgroups to evaluate the potential projects described in the three previous rounds; evaluation criteria specifically included resource requirements. Evaluation posters were created and reviewed by the entire group.

Day Three started with the creation of an implementation matrix, synthesizing the evaluation posters and ranking projects based on overall priority. Participants then collaborated to distill the values, goals and objectives that should inform funding strategies.

The workshop closed with discussion of next steps and thanks to participants and organizers. A special acknowledgement goes to the consulting firm KnowInnovation, whose expertise and facilitation of the workshop were invaluable.

APPENDIX D

Project ideas, evaluation metrics, and ratings

A variety of workforce-related project ideas, some already underway in our community or in another STEM discipline, and some just envisioned, were articulated at the INGenIOuS workshop. In addition, several metrics were used by workshop participants to rate the projects on a variety of different dimensions. The project ideas, evaluation metrics, and ratings assigned by participants are summarized informally in this appendix.

Each project summary includes a designation of "Tried" or "Tried: Unknown" to indicate whether or not workshop participants were aware of any such a project that had been attempted in some STEM discipline.

The final table in this appendix compares all projects across all metrics.

Project 1: BOLD (**B**uy-in **o**f A**l**ternative/External I**d**eas)

Summary: BOLD is a 3-part program to bring novel external ideas and expertise to a mathematics/statistics department. We propose a resource-sharing/ranking site, the creation of professional consultants, and advisory boards for departments.

Value added: We encourage change by making it easier and distributing work. This will create a more dynamic mathematical community on the leading edge of change.

Motivating problem: Departments get stuck in the status quo; curriculum, technology, outreach projects do not advance readily. We should be on the leading edge, not trailing. We should change culture to be open to new technology, pedagogy, etc.

An obstacle to change: Faculty time is limited. Priorities are not always toward the change-many reasons for this. Autonomy, culture (advice = interference)/lack of interest/prioritizing research ahead of other things (due to funding bodies and culture)

Solution: Bring in outside help; find ways to get people to listen to this person or group. Success leads to interest and respect. Employ a three-part strategy:

(a) Professional consultants
(b) Advisory board
(c) Web-based resource for sharing and review

Tried: Some engineering programs employ an advisory board.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	BOLD Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Uncertain
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	VH
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	5
Broadening Participation	Low, Medium, Medium+, or High	Low
Sustainability	Low, Medium, or High	Low
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Low
Stickiness	Narrow (1) to Widely adoptable (5)	2
Scalability	Does not scale easily (1) to Highly Scalable (5)	2
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Replicable
Faculty Involvement	Few Faculty (1) to Entire Department (3)	2
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	Low
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	1
Practical	Very Practical (1) to Not Practical (5)	4
Investment over time (Manpower)	Low (1) to High (16)	3
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 2: Out of the Academy

Summary: Program to move through awareness to understanding and collaboration among academy, business, government, and industry, resulting in mutual benefits through systemic curriculum and pedagogy evaluation.

Value added:

(a) Curriculum change and pedagogical transformation: more applications, modeling, problem solving
(b) Integration of relevant technology in teaching and learning
(c) Build awareness: bring B, I, and G into classroom through visiting lecture program
(d) Internships, job opportunities, faculty exchange programs
(e) Workshops for faculty and industry representative

Tried: Unknown

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Out of Acad Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	H
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Low
Sustainability	Low, Medium, or High	High
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	3
Scalability	Does not scale easily (1) to Highly Scalable (5)	2
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	2
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	5
Value	Low, Medium, or High	High
Doability	Low, Medium, or High	Low
Inspiring	Not inspiring (1) to Inspiring (5)	4
Practical	Very Practical (1) to Not Practical (5)	4
Investment over time (Manpower)	Low (1) to High (16)	10
Likelihood of Success	Low, Medium, or High	Low
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 3: Seeds and Stems

Summary: Seeds and Stems will provide a mechanism for student teams to come together and develop new businesses grounded in STEM technologies. Universities will provide facilities (space, computational resources, etc.) and seed funding in the form of reduced tuition. In exchange, teams agree to provide the university with a stake in the resulting business.

A Board of Advisors would come from local industry and university business development. Faculty mentors would be assigned.

Benefits:

(a) Enrich multi-disciplinary collaborations
(b) Provide practical training
(c) Attract under-represented students in STEM through tuition rebates
(d) Secondary effects through providing additional STEM jobs as the business grows

Tried: Clarkson University currently has a similar program.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Seeds Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	M
Impact (# of individuals)	Small, Medium, or Large	Small
Measurability	Easy to assess results (1) to Difficult to assess results (5)	1
Broadening Participation	Low, Medium, Medium+, or High	Low
Sustainability	Low, Medium, or High	High
Cost	Low, Medium, or High	Medium
New Resources Needed	Low, Medium, or High	High
Stickiness	Narrow (1) to Widely adoptable (5)	5
Scalability	Does not scale easily (1) to Highly Scalable (5)	1
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Replicable
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	5
Practical	Very Practical (1) to Not Practical (5)	5
Investment over time (Manpower)	Low (1) to High (16)	12
Likelihood of Success	Low, Medium, or High	Low
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 4: ELLN (Experiential Learners Leader Network)

Summary: Create a national network of experiential learner leaders who would develop and disseminate models, approaches, and networks for internships, service-learning, projects, job placement, soft skills, programming, interdisciplinary skills, curricular changes, co-curricular activities, to include members from academic (collegiate, secondary education teachers and counselors), corporate, NGO, and other settings.

Value added: Increase recruitment, retention, placement, and marketability, enhance learning, breadth, and job preparation of students

Problem addressed: Not enough undergraduate student access to experiential learning (internships/service learning, projects, job placement) from freshman through senior years.

Strategies: Must improve students' soft skills, programming, and interdisciplinary learning skills. Curricular change may be needed. Among specific objectives:

(a) develop and disseminate models of best practice of internships, service learning, projects
(b) create national network of EL leaders who would do the developing and dissemination
(c) Idea box for housing ideas (network includes all stakeholders)

Who benefits? Students, departments, employers, NGOs, faculty, schools, parents, secondary education.

Tried: Brigham Young University currently has a similar program.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	ELLN Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	M
Impact (# of individuals)	Small, Medium, or Large	Large
Measurability	Easy to assess results (1) to Difficult to assess results (5)	3
Broadening Participation	Low, Medium, Medium+, or High	Medium
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	Medium
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	3
Scalability	Does not scale easily (1) to Highly Scalable (5)	4
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	All or Nothing
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	2
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	7
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 5: MIA: Mathematical Sciences in Action (Marketing Campaign for the General Public)

Summary: Develop a "viral" marketing campaign to develop cultural support for the mathematical sciences.

Value added: Increase recruitment and retention of students. Benefits the general public: K-12 students, teachers, legislators, parents, STEM majors, and graduate students. Offers cultural support for mathematical and statistical science and STEM fields.

Problem to address: Usefulness of mathematical sciences has low visibility among general public.

Strategies: Use professional advertising agencies, social media, TED talks, YouTube, "math reality TV", etc.

Tried: Unknown, at least in STEM. Beyond STEM, viral marketing campaigns are used for movies.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	MIA Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	No
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	L
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	3
Broadening Participation	Low, Medium, Medium+, or High	Medium+
Sustainability	Low, Medium, or High	Low
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Low
Stickiness	Narrow (1) to Widely adoptable (5)	3
Scalability	Does not scale easily (1) to Highly Scalable (5)	5
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	All or Nothing
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Low
Inspiring	Not inspiring (1) to Inspiring (5)	4
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	13
Likelihood of Success	Low, Medium, or High	Medium
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 6: National Network for Broadening Faculty Experience

Summary: Faculty have too narrow views of career paths for math scientists; project would offer breadth.

Value added:

(a) Improve versatility and vitality of mathematical sciences community
(b) Offer broader opportunities to students
(c) Shift academia vs. industry employment balance from 75-25 to 50-50

Strategies and resources:

(a) Workshops for Mathematics and Statistics faculty involving BIG professionals
(b) Online community and background materials
(c) Faculty and industry representatives in departments serve as career advisors
(d) Seminars to inform students

Tried: Brigham Young University currently has a similar program.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Nat Netwk Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	L
Impact (# of individuals)	Small, Medium, or Large	Small
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Medium
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	Low
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	5
Scalability	Does not scale easily (1) to Highly Scalable (5)	3
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	2
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	Low
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	2
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	11
Likelihood of Success	Low, Medium, or High	Medium
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 7: BIG IDEAS: B(usiness/old) I(ndustry/nnovative) G(ovt/lobal) I(nnovative) D(ata) E(xperiential) A(uthentic) S(imulation)

Summary: We propose a curriculum and mode of delivery: computation, simulation, and visualization as the foundation of mathematical thinking. Advanced courses build on these skills and culminate in big data competitions. Delivery is via technology-enhanced modules (e.g. MOOCs). Social community is created through university consortia and BIG partnerships.

Value added: Synthesizes probability, statistics, math modeling. Serves as a starting point and an entire approach to mathematical sciences curriculum, or as a terminal course. Approach enables greater success for a larger community of students. Mathematical institutes would enable BIG connections and university consortia.

Strategies: Build a BIG mentor network; encourage BIG open houses and BIG recruiting at mathematical conferences and at institutes. (See, e.g., MUDAC.org)

Tried: Examples include Kaggle competitions, the X Prize Foundation, the KDD Cup, and the Big Data competition.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	BIG IDEAS Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	L
Impact (# of individuals)	Small, Medium, or Large	Large
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Medium+
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	5
Scalability	Does not scale easily (1) to Highly Scalable (5)	5
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	3
Student Involvement	Few Students (1) to All Students (3)	3
Time to implement	Shorter (1) to Longer (5)	5
Value	Low, Medium, or High	High
Doability	Low, Medium, or High	Low
Inspiring	Not inspiring (1) to Inspiring (5)	5
Practical	Very Practical (1) to Not Practical (5)	5
Investment over time (Manpower)	Low (1) to High (16)	6
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 8: Charting the Future

Summary: Mathematics and statistics programs at all levels will provide a second 'leg' of experience/depth to enhance student competence and qualifications for a range of workforce options. This could be experience on campus, at another department, in industry, government or business. Part of this program will include a clearinghouse of options, a network exchange program for graduate students.

Value added:

(a) Graduates become more competitive for a greater array of opportunities.
(b) Graduates will have had experiences across more disciplines.
(c) Improved job placement and retention in mathematics and statistics fields.

Tried: An example of a similar idea is the undergraduate minor.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	ChartFuture Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Uncertain
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	H
Impact (# of individuals)	Small, Medium, or Large	Small
Measurability	Easy to assess results (1) to Difficult to assess results (5)	1
Broadening Participation	Low, Medium, Medium+, or High	Medium
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	Medium
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	3
Scalability	Does not scale easily (1) to Highly Scalable (5)	3
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Replicable
Faculty Involvement	Few Faculty (1) to Entire Department (3)	2
Student Involvement	Few Students (1) to All Students (3)	2
Time to implement	Shorter (1) to Longer (5)	2
Value	Low, Medium, or High	High
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	3
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	8
Likelihood of Success	Low, Medium, or High	Medium
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 9: INGenIOuS Corps – STEM Solutions for America

Summary: INGeniOUS Corps brings together groups of students from different STEM and domain-specific disciplines to develop technology addressing a pressing social issue at the university or community level. Could be funded by foundations, tech companies, venture capitalists.

Benefits:

(a) Student practical training, internships, and job opportunities
(b) Improved recruitment and retention of under-represented students
(c) Increased awareness and appreciation for STEM capabilities
(d) Effects modernization of mathematics sciences curriculum
(e) Enables social good

Strategies: For undergraduates: semester-long courses and/or summer internships; STEM-focused interdisciplinary service projects for mathematical sciences majors. For graduates: opportunity to take a 1-2 year full-time position after graduation.

Project examples:

(a) Identifying highest needs for social welfare agencies using data
(b) Building apps for matching students and tutors
(c) Environmental projects

Value added:

(a) Broadens perspective of what mathematical sciences is in the 21st century
(b) Brings mathematics to the masses; demonstrates value to society
(c) Interdisciplinary work
(d) As with internships, participants make contact with employers
(e) Could morph into smaller projects appropriate for community colleges/K-12
(f) Has potential to influence public policy
(g) Emphasizes importance of computational mathematics
(h) Attractiveness to underrepresented minorities

Tried: Examples include Teach for America, Code for America, the Peace Corps, and Data Science for Global Good.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	ING Corps Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	M
Impact (# of individuals)	Small, Medium, or Large	Small
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Medium
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	High
Stickiness	Narrow (1) to Widely adoptable (5)	4
Scalability	Does not scale easily (1) to Highly Scalable (5)	5
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Replicable
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	3
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	5
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	5
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 10: Bricolage (Construction of a work from a diverse range of things that happen to be available)

Summary: Create a community-owned and -run mathematics course materials publisher/distributor. Major societies and designers would agree to create and use content.

Value added: Provide direction to faculty/departments/professional organizations; reduce influence of publishers (status quo, rapid edition updates, high cost); reduce redundant efforts; include non-text book resources; incubate transformative approaches; facilitate curriculum reform.

Tried: Unknown

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Bricolage Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Uncertain
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	VL
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	1
Broadening Participation	Low, Medium, Medium+, or High	Low
Sustainability	Low, Medium, or High	High
Cost	Low, Medium, or High	Low
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	2
Scalability	Does not scale easily (1) to Highly Scalable (5)	2
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	3
Student Involvement	Few Students (1) to All Students (3)	3
Time to implement	Shorter (1) to Longer (5)	1
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	1
Practical	Very Practical (1) to Not Practical (5)	3
Investment over time (Manpower)	Low (1) to High (16)	16
Likelihood of Success	Low, Medium, or High	Medium
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 11: Symbiotic Pathways through Mathematics/Statistics to Solve Global Challenges

Summary: Create a viable mathematics/statistics community to address global challenges (health, education, information, environment and energy, etc.) This community has multiple pathways reaching in and reaching out.

Value added:

(a) Retains and increases the STEM pool with multiple entry points.
(b) Improves the perception of mathematics and statistics as partner disciplines.
(c) Cost effectiveness
(d) Bridges users and majors of mathematics and statistics
(e) Enables "sideways" entry into STEM

Tried: Unknown

Evaluation metrics and ratings (on the following page):

Criterion	Scale	SymbPathways Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	M
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	4
Broadening Participation	Low, Medium, Medium+, or High	High
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	2
Scalability	Does not scale easily (1) to Highly Scalable (5)	5
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	2
Time to implement	Shorter (1) to Longer (5)	5
Value	Low, Medium, or High	Low
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	2
Practical	Very Practical (1) to Not Practical (5)	2
Investment over time (Manpower)	Low (1) to High (16)	9
Likelihood of Success	Low, Medium, or High	Low
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 12: Inno-versity: The New Frontier for Transformative Research

Summary: New academic model would bring interdisciplinary teams of students together to address a societal problem each year, using mathematics/statistics skills.

Value added: Harness student enthusiasm; address important problems; mathematics engagement; collaboration with STEM; exposure to diverse career paths.

Tried: An example is the series of Gordon Research Conferences.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Inno-versity Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	H
Impact (# of individuals)	Small, Medium, or Large	Small
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	High
Sustainability	Low, Medium, or High	Low
Cost	Low, Medium, or High	Medium
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	4
Scalability	Does not scale easily (1) to Highly Scalable (5)	5
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Replicable
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	1
Value	Low, Medium, or High	Low
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	3
Practical	Very Practical (1) to Not Practical (5)	5
Investment over time (Manpower)	Low (1) to High (16)	1
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	5--10

Project 13: GEMS (Growing Employment in Mathematical Sciences)

Summary: Aiming for cultural change in the mathematical sciences, the project would embrace and celebrate the many accomplishment of mathematical scientists.

Problems addressed: Lack of recognition and support of students taking non-academic career paths; lack of faculty/student/public awareness of opportunities in mathematics sciences.

Who is involved?

(a) Students K-20
(b) Faculty
(c) Employers
(d) Public
(e) Institutions
(f) Alumni and foundations

Strategies, mechanisms:

(a) Project NExT-like deployment would influence young faculty
(b) Life-long mentoring
(c) Develop mathematics genealogy for non-academic careers
(d) Offer prizes for non-academic mathematics research/innovation
(e) Internships and industry projects for student and faculty
(f) Undergraduate research projects
(g) Promote experiential learning; facilitate connections
(h) Track careers of and engage alumni
(i) Reward faculty involvement

Tried: Unknown

Evaluation metrics and ratings (on Evaluation metrics and ratings (on the following page):

Criterion	Scale	GEMS Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	No
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	L
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	3
Broadening Participation	Low, Medium, Medium+, or High	Medium+
Sustainability	Low, Medium, or High	High
Cost	Low, Medium, or High	Medium
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	3
Scalability	Does not scale easily (1) to Highly Scalable (5)	4
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	3
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Low
Inspiring	Not inspiring (1) to Inspiring (5)	5
Practical	Very Practical (1) to Not Practical (5)	5
Investment over time (Manpower)	Low (1) to High (16)	14
Likelihood of Success	Low, Medium, or High	Low
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	> 10

Project 14: INGenIOus "Seal of Approval"

Summary: Departments would become "INGenIOus certified" by meeting specific criteria.

Problem addressed: Too many ideas for change are at individual level. Full departments should be involved.

Value added:

(a) Increased participation/dissemination; once certified, departments take responsibility to inform and encourage other departments to seek certification
(b) Effective implementation/institutional change
(c) External and internal recognition of department and individual faculty work
(d) Project has high level of impact and is scalable and sustainable
(e) Certification would aid assessment for accreditation
(f) Benefits stakeholders at all levels

Components: BIG interns, K-12 connections, UG research groups, new introductory courses

Tried: An example is the accreditation process in higher education.

Evaluation metrics and ratings (on the following page):

Criterion	Scale	SealApproval Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Uncertain
Community Investment	No, Uncertain (not clear if community investment required), or Yes	No
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	VH
Impact (# of individuals)	Small, Medium, or Large	Large
Measurability	Easy to assess results (1) to Difficult to assess results (5)	1
Broadening Participation	Low, Medium, Medium+, or High	High
Sustainability	Low, Medium, or High	High
Cost	Low, Medium, or High	Low
New Resources Needed	Low, Medium, or High	Low
Stickiness	Narrow (1) to Widely adoptable (5)	2
Scalability	Does not scale easily (1) to Highly Scalable (5)	1
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	All or Nothing
Faculty Involvement	Few Faculty (1) to Entire Department (3)	3
Student Involvement	Few Students (1) to All Students (3)	1
Time to implement	Shorter (1) to Longer (5)	1
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	Medium
Inspiring	Not inspiring (1) to Inspiring (5)	2
Practical	Very Practical (1) to Not Practical (5)	1
Investment over time (Manpower)	Low (1) to High (16)	2
Likelihood of Success	Low, Medium, or High	High
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 15: Projects to Make Math Cool

Summary: The project would develop/assemble coordinated resources for a flexible problem/project-driven curriculum that is widely adopted in many forms.

Value added: Combat prevailing perceptions of mathematics: isolated, boring, not cool, disconnected, difficult. Improve recruitment, retention, and students' job readiness for a broader spectrum of careers. Augment traditional curricula with exposure to many areas of applications

Tried: An example is the shared repository of Undergraduate Mathematics and its Applications (UMAP).

Evaluation metrics and ratings (on the following page):

Criterion	Scale	Cool Math Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Uncertain
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Uncertain
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	M
Impact (# of individuals)	Small, Medium, or Large	Medium
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Medium+
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	Low
New Resources Needed	Low, Medium, or High	Low
Stickiness	Narrow (1) to Widely adoptable (5)	4
Scalability	Does not scale easily (1) to Highly Scalable (5)	3
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	1
Student Involvement	Few Students (1) to All Students (3)	2
Time to implement	Shorter (1) to Longer (5)	3
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	2
Practical	Very Practical (1) to Not Practical (5)	4
Investment over time (Manpower)	Low (1) to High (16)	15
Likelihood of Success	Low, Medium, or High	Medium
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	< 5

Project 16: Personalized Study for STEM Talent (PSST): What's the secret?

Summary: A dynamic and customizable program of quantitative problem solving is proposed that replaces traditional majors and semester long courses. This is comprised of a hybrid of community and competencies to develop quantitative and computational capacities needed for the workforce. Competencies are developed through a variety of technology-enabled modules that are integrated and extended through long-term interdisciplinary projects. These are guided by faculty who continually develop these modules and projects in partnership with business, industry and government.

Value Added: Modern and nimble curriculum is developed to meet the needs of the workforce.

Problem addressed: There is a mismatch between student knowledge and skills and workforce needs.

Strategies:

(a) Modules, not full courses, support quantitative and computational problem solving
(b) Competencies, not majors, are developed in community
(c) Dynamic, not fixed, major and curriculum that evolves with workforce needs
(d) Technology enabled – (not all or none)
(e) Faculty are partnered with BIG (horizontally) not pipeline (vertically)
(f) Extended projects and work throughout

Tried: Unknown

Evaluation metrics and ratings (on the following page):

Criterion	Scale	PSST Ratings
Interdisciplinary	No, Uncertain (not clear if interdisciplinary), or Yes	Yes
Community Investment	No, Uncertain (not clear if community investment required), or Yes	Yes
Investment	Very Low (VL), Low (L), Medium (M), High (H), or Very High (VH)	H
Impact (# of individuals)	Small, Medium, or Large	Large
Measurability	Easy to assess results (1) to Difficult to assess results (5)	2
Broadening Participation	Low, Medium, Medium+, or High	Medium+
Sustainability	Low, Medium, or High	Medium
Cost	Low, Medium, or High	High
New Resources Needed	Low, Medium, or High	Medium
Stickiness	Narrow (1) to Widely adoptable (5)	1
Scalability	Does not scale easily (1) to Highly Scalable (5)	1
Replicability	Replicable, Pilot (can be piloted, then scaled), or All or Nothing (requires national implementation)	Pilot
Faculty Involvement	Few Faculty (1) to Entire Department (3)	3
Student Involvement	Few Students (1) to All Students (3)	3
Time to implement	Shorter (1) to Longer (5)	5
Value	Low, Medium, or High	Medium
Doability	Low, Medium, or High	High
Inspiring	Not inspiring (1) to Inspiring (5)	3
Practical	Very Practical (1) to Not Practical (5)	2
Investment over time (Manpower)	Low (1) to High (16)	4
Likelihood of Success	Low, Medium, or High	Low
Time Frame	Less than 5 years (< 5), 5 to 10 years (5--10), or More than 10 years (>10)	> 10

Criterion	Ratings: Comparison across all projects							
	BOLD	Out of Acad	Seeds	ELLN	MIA Ratings	Nat Network	BIG IDEAS	Chart Future
Interdisciplinary	Uncertain	Yes	Yes	Yes	No	Yes	Yes	Uncertain
Community Investment	Uncertain	Yes	Yes	Yes	Yes	Uncertain	Uncertain	Yes
Investment	VH	H	M	M	L	L	L	H
Impact (# of individuals)	Medium	Medium	Small	Large	Medium	Small	Large	Small
Measurability	5	2	1	3	3	2	2	1
Broadening Participation	Low	Low	Low	Medium	Medium+	Medium	Medium+	Medium
Sustainability	Low	High	High	Medium	Low	Medium	Medium	Medium
Cost	High	High	Medium	Medium	High	Low	High	Medium
New Resources Needed	Low	Medium	High	Medium	Low	Medium	Medium	Medium
Stickiness	2	3	5	3	3	5	5	3
Scalability	2	2	1	4	5	3	5	3
Replicability	Replicable	Pilot	Replicable	All or Nothing	All or Nothing	Pilot	Pilot	Replicable
Faculty Involvement	2	2	1	1	1	2	3	2
Student Involvement	1	1	1	1	1	1	3	2
Time to implement	2	5	2	2	2	2	5	2
Value	Low	High	Medium	Medium	Medium	Low	High	High
Doability	High	Low	Medium	Medium	Low	Medium	Low	Medium
Inspiring	1	4	5	2	4	2	5	3
Practical	4	4	5	3	3	3	5	3
Investment over time (Manpower)	3	10	12	7	13	11	6	8
Likelihood of Success	High	Low	Low	High	Medium	Medium	High	Medium
Time Frame	< 5	5--10	5--10	5--10	5--10	< 5	5--10	< 5

Criterion	Ratings: Comparison across all projects							
	ING Corps	**Brico-lage**	**Symb Path**	**Inno-versity**	**GEMS**	**SealAp-proval**	**Cool Math**	**PSST Ratings**
Interdisciplinary	Yes	Uncertain	Yes	Yes	No	Uncertain	Uncertain	Yes
Community Investment	Yes	Uncertain	Yes	Yes	Uncertain	No	Uncertain	Yes
Investment	M	VL	M	H	L	VH	M	H
Impact (# of individuals)	Small	Medium	Medium	Small	Medium	Large	Medium	Large
Measurability	2	1	4	2	3	1	2	2
Broadening Participation	Medium	Low	High	High	Med+	High	Med+	Med+
Sustainability	Medium	High	Medium	Low	High	High	Medium	Medium
Cost	High	Low	High	Medium	Medium	Low	Low	High
New Resources Needed	High	Medium	Medium	Medium	Medium	Low	Low	Medium
Stickiness	4	2	2	4	3	2	4	1
Scalability	5	2	5	5	4	1	3	1
Replicability	Replicable	Pilot	Pilot	Replicable	Pilot	All or Nothing	Pilot	Pilot
Faculty Involvement	1	3	1	1	1	3	1	3
Student Involvement	1	3	2	1	1	1	2	3
Time to implement	3	1	5	1	3	1	3	5
Value	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium
Doability	Medium	High	High	High	Low	Medium	High	High
Inspiring	5	1	2	3	5	2	2	3
Practical	3	3	2	5	5	1	4	2
Investment over time (Manpower)	5	16	9	1	14	2	15	4
Likelihood of Success	High	Medium	Low	High	Low	High	Medium	Low
Time Frame	< 5	< 5	< 5	5--10	> 10	< 5	< 5	> 10

APPENDIX E

Acronyms

INGenIOuS: **I**nvesting in the **N**ext **Gen**eration through **I**nnovative and **Ou**tstanding **S**trategies.

AMS: **A**merican **M**athematical **S**ociety

ASA: **A**merican **S**tatistical **A**ssociation

BIG: **B**usiness, **I**ndustry, and **G**overnment

MAA: **M**athematical **A**ssociation of **A**merica

MOOC: **M**assively **O**pen **O**nline **C**ourse

NSF: **N**ational **S**cience **F**oundation

PCAST: **P**resident's **C**ouncil of **A**dvisors on **S**cience and **T**echnology

SIAM: **S**ociety for **I**ndustrial and **A**pplied **M**athematics

STEM: **S**cience, **T**echnology, **E**ngineering, and **M**athematics