Mathematical Sciences Internships: Building Career Pathways
Report from the September 1-2, 2015
NSF-IPAM Mathematical Sciences Internship Workshop

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SUMMARY RECOMMENDATIONS
NSF-IPAM Mathematical Sciences Internship Workshop

This report reflects discussions and recommendation from the September 1-2, 2015 NSF-IPAM Mathematical Sciences Internship Workshop held at the Institute for Pure and Applied Mathematics (IPAM) at UCLA. The workshop was organized by Russel Caflisch, Mathematics, UCLA; Alan Lee, VP of Engineering, Advanced Micro Devices (AMD); Rachel Levy, Mathematics, Harvey Mudd College (facilitator) and James L Rosenberger, Statistics, Penn State. The diverse group of participants brought perspectives from academic (college/university, public/private), business (large/small) and governmental institutions as well as many areas of the mathematical sciences.

The goal of the two-day workshop was to discuss recommendations for infrastructure and programs that could:

- increase the number of internships targeting mathematical sciences students
- open the internship pipeline to a diverse group of students
- provide assistance with timing and logistics for undergraduates, graduate students and postdocs in pure and applied mathematics
- provide training to prepare mathematical sciences students for internships
- develop viable models of how internships best work for mathematical sciences students, postdocs and faculty and for industry/government

During the workshop participants spent two sessions in one of the following working groups: support, training, logistics, recruiting, culture. They also rotated to two other groups, participated in a charrette to respond to general questions, and provided comments in several all-group sessions. With the intentional overlap between topics and exchange between members of different groups, many ideas arose which resonated across the groups. This report represents central ideas that had strong support, as well as questions and considerations raised by the participants.

The following recommendations resonated across the working groups on support, training, logistics, recruiting, and culture. A target of 1000 graduate internships per year was suggested to meet the demand for internships arising from the strong production of Mathematics PhDs, and the large numbers of students pursuing BIG (Business, Industry, Government) careers after the undergraduate and Master's levels. The recommendations are related as a distributed network, with different goals at each level.

Distributed Network Internship Initiative

National level: Create a national network to increase internship information exchange, data collection, access and opportunities

- Design and implement a data-gathering project to inform a picture of the mathematical sciences internship landscape and provide baseline data for new initiatives.
- Provide communication and coordination of best practices, training materials and opportunities, models for local programs, and media to aid regional and local outreach efforts.
- Build a national network of individuals, companies, government labs, academic institutions, math societies and mathematical sciences institutes to exchange information and work together to increase and advertise internship opportunities.
- Develop funding mechanisms and pursue funding for mathematical sciences internship stipends (seed money), internship training and internship development.

Regional level: Establish regional internship centers to build internship contacts and organize training opportunities

- Build internship contacts and opportunities in the region
- Offer centralized training (that could be replicated locally), such as short courses in programming, soft skills and data.
- Hire internship development staff to serve as liaisons between local institutions and potential internship sites and to promote mathematical sciences internships in BIG by communicating how mathematical sciences students make contributions.

Local academic level: Encourage and enable student participation in internships in mathematical sciences departments

- Encourage students to pursue training and internships.
- Disseminate information from national and regional organizations.
- Identify the department chair, director of graduate study, or an interested faculty member to build local institutional mechanisms for internships.

Roadmap: The initial phase of this initiative would include the national network and a few regional initiatives (perhaps located in the eastern/southern, central/midwestern and western parts of the US). The first priority for the national network would be to build the network itself, gather and disseminate information (such as data, best practices and internship opportunities) and seek sponsorship from BIG to become self-sustaining. The first priority for the regional centers would be to identify participating institutions, provide training, and build academic-BIG connections in the region. New regional centers would be added, with promising locations informed by areas of need identified by the national network.

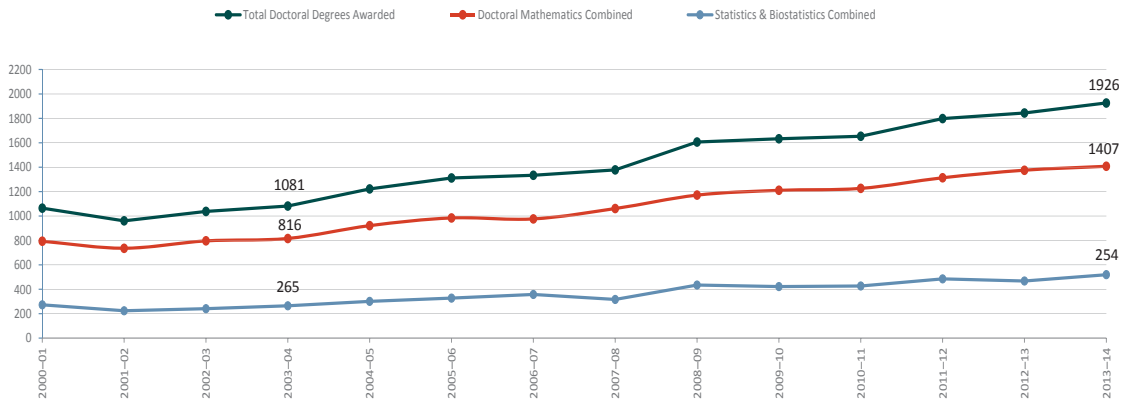
BACKGROUND

The mathematical sciences workforce landscape

A strong motivation to consider the role of internships in mathematical sciences training arises from the job market landscape. One source of information tracking employment is the Annual Survey of the Mathematical Sciences. The following data are from the "Report on the 2013-2014 New Doctoral Recipients", published in the Notices of the AMS, August 2015. There are 315 PhD granting institutions in the US, and there was a 100% response rate to the survey.

The number of PhDs produced in the US has roughly doubled in the past ten years (see Figure A.2 below). However, the number of tenure-track or permanent academic jobs is decreasing.

Figure A.2: New PhDs Awarded by Group



From the *2013-14 Annual Survey of the Mathematical Sciences*

Of the 1926 PhDs, the employment picture included:

US employed: 1412
Non-US employed: 231
Seeking employment: 93
Not seeking employment: 13
Unknown: 177

The employed numbers include postdoctoral, adjunct and tenure-track academic positions as well as positions in business, government and other areas. Of those employed, 626 of them (38%) took postdoctoral positions. About 7% of new US citizen PhDs are unemployed.

Using the numbers above as the basis we can roughly estimate the number of job seekers as the PhDs who sought a permanent position, but decided on a postdoc (about 150 if we say the fraction is ¼) plus the 93 new PhDs seeking employment and some of the 177 PhDs in unknown positions. There are additional job demands from PhD students who matriculated but did not finish (approximately 5 times the number of PhDs finishing, or about 10,000).

Since there are about 2000 students graduating each year, if we wanted to target, for example, 25% of 2nd and 3rd year students to place them in internships, we would need around 1000 internship positions.

The employment numbers in Business Industry and Government were as follows: In Business/Industry, 181 were hired from Statistics and Biostatistics, while 228 were hired from Math and Applied Math. In Government, 22 were hired from Statistics and Biostatistics and 55 from Math and Applied Math.

Academic and research institutes hired 926 and 234 people, respectively (not all of them new PhDs.) Of the 926 people hired in academic institutions, most were hired for jobs in Masters, Bachelor, and 2-year institutions. In Math and Applied Math 740 out of the 845 tenure track jobs were filled. In Statistics and Biostatistics, 104 out of the 147 tenure track jobs were filled.

What we don't yet know is how internships play a role in these employment numbers. In the infrastructure section of this report, we discuss in greater detail the need for data collection about internship supply, demand and impact.

INFRASTRUCTURE

As outlined in the executive summary, there was broad support across the working groups for a new national organization with regional hubs. Participants with strong industrial mathematics programs at their institution noted that they have staff devoted to corporate relations and project recruitment. There was consensus that new staff positions at the national, regional and local levels can help create and promote mathematical sciences internships. The staff would serve as liaisons between BIG and academic institutions and should have industrial experience and familiarity with mathematics. They do not necessarily need PhDs to initiate and facilitate new relationships and opportunities but they should be able to communicate with BIG, especially people who have not previously hired mathematical sciences students, what they can contribute.

While there was consensus on the value of nationally coordinated regional hubs, it was not clear whether the regional centers should be located at the mathematical sciences institutes, at academic institutions or in some other kind of location, such as a research park. The institutes are seen as belonging to the mathematics community at large, they are already established, and people travel to them

regularly. However, the institutes are not permanently funded, they don't necessarily have internships as part of their founding mission, and they are not geographically distributed. As a regional hub, a single academic or BIG institution might not be seen as serving the broad mathematical sciences community. The primary concern was that whatever infrastructure is created serves the mathematical sciences community as a whole.

Here we consider an extra level of detail in the outline of responsibilities at the national, regional and local levels than is contained in the executive summary:

National level:

- Initiate a data-gathering project to inform a picture of the mathematical sciences internship landscape and provide baseline date for new initiatives.
- Provide communication and coordination of best practices, training materials and opportunities, models for local programs, and media to aid regional and local outreach efforts.
    - Share information about intellectual property issues and practices
    - Recommend courses for inclusion in Masters and PhD programs to support internship training
    - Serve as an external visiting committee or consultant to universities to facilitate internship program development
    - Identify and connect with university research parks to participate in regional and local efforts
    - Provide information for faculty and students who do not have resources or support in their own institutions.
    - Develop short courses to be offered to faculty and students at conferences
    - Provide information about online industry challenge problems
    - Provide career information: sample documents such as CV, Resume, and Cover letters, and career advice columns
    - Work with the societies to provide training/information at the JMM sessions for Directors of Graduate Studies
- Build national network of individuals, companies, government labs, academic institutions, math societies and mathematical sciences institutes to exchange information and work together to increase and advertise internship opportunities.
    - Identify appropriate committees within professional societies to help with these efforts, including cultural changes in attitudes towards BIG jobs.
    - Create networks of Directors of mathematical sciences institutes and the Directors of Graduate Studies in Math/Stat departments. Host annual meetings to allow them to share opportunities and success stories.
    - Organize sessions at national conferences where students can share BIG internship projects.

- Develop funding mechanisms and pursue funding for mathematical sciences internship stipends (seed money), internship training and internship development.

In the draft review process several individuals commented on whether the national network should be web-based or located in a physical location (such as an institute, academic institution or mathematics society). There was support for both ideas, as in the representative quotes below (included with permission).

"A national network to support BIG internships for mathematics PhD students is compelling and complements very well the work we have been doing with such internships locally at Urbana-Champaign." – Matthew Ando, Professor and Chair, Department of Mathematics, University of Illinois at Urbana-Champaign

If there is a national level program conducting both the national level efforts and coordinating the regional efforts, then I believe a physical entity is required. There may be a strong virtual component to it, but you still need someone in charge of the program with support staff. – Allen Butler, Daniel H. Wagner Associates

Regional level:

- Build internship contacts and opportunities in the region.
    - Learn which regional BIG institutions have the demand and capacity for new internships
    - Network with nodes at diverse geographic and types of institutions
- Offer centralized training (that could be replicated locally).
    - Organize industry "study groups" (week long problem solving workshops)
    - Actively recruit participants from underrepresented groups.
    - Provide training opportunities (such as bootcamps) that could draw students from a wide variety of institutions.
- Hire Internship Development Staff to serve as liaisons between local institutions and potential internship sites and to promote mathematical sciences internships in BIG.
    - Identify new BIG partners
    - Communicate with people who have not previously hired mathematical sciences students what they can contribute in BIG.

Local academic level:

- Encourage students to pursue training and internships.
    - Encourage student clubs/groups to host alumni career panels with BIG representatives
    - Invite speakers from BIG for seminars and colloquia
    - Interact with career services to help them advise mathematics students about BIG opportunities. Career services can also help to

make contact with local and regional BIG institutions and let mathematics departments know when institutions are recruiting for other departments (such as engineering).
    - Hire documentary studies students to make videos about successful internships and collaborations.
    - Teach students the types of search terms that will help them identify appropriate internships
    - Communicate to students seeking BIG internships and jobs that they need not be intimidated by job titles/project descriptions/job requirements
    - Help students balance timing of preparation for internships and qualifying exams.
    - Pay for bootcamps/training and incentivize professional development (say in data science)
    - Encourage peer-to-peer training
- Disseminate information from national and regional organizations.
    - Provide Directors of Graduate Studies with fliers/URLs to help them advise students about internship opportunities
    - Share outreach efforts such as the videos in Appendix E.
    - Run student industrial mathematics training workshops locally.
    - Develop courses with accelerated introductions to technical areas.
    - Work with corporate relations and advancement offices to connect with BIG partners.
    - Share information with interested faculty and support them (training/time/funding) to connect with industry
- Identify the department chair, director of graduate study, or an interested faculty member as the local person to build institutional mechanisms for internships. This local contact can catalyze these types of efforts:
    - Identify potential on campus internship placements in other departments, labs or institutes (such as LISA at VA Tech, a statistical collaboration laboratory).
    - Gather data from alumni about their careers.
    - Encourage students to ask prospective/current advisor what is the best year to do an internship.
    - Maintain connections with alumni already in industry (bring in for networking, career panels, mock interviews).
    - Consider whether to offer professional Master's degrees.

INTERNSHIP LOGISTICS AND SUPPORT

Internship Jobs Site

Workshop participants expressed enthusiasm for a mathematical sciences internship jobs site where students post resumes and companies post open positions. Representatives from businesses and government labs at the SIAM Computational Sciences and Engineering (CS&E) job fair also unanimously

supported such a site, both to help mathematical sciences students pursue internships nationwide and to help them recruit the students. At CS&E the recruiters noted that they serve as mentors but do not write or post job listings. In larger organizations, Human Resources departments write the job descriptions and budget for postings. The CS&E recruiters also indicated that they are quite involved in the recruitment process – they look at the work published by the students, interview them carefully and look for signs of initiative, target skills and communication proficiency. They sometimes need certain capabilities, but often can find or design a project to take advantage of a student's expertise and interests. The participants noted that a centralized application process could open internships opportunities to a wide variety of students. An application process for mathematical sciences internships could improve access to internships for students who are not from the more elite schools targeted by recruiters. It would also enable students to find internships in a geographic region of interest. Some participants thought it best that the BIG institutions screen applications. Others noted that centralized screening, as in the MITACS framework, could help small and medium hiring groups with no current employees in the mathematical sciences figure out which mathematicians could best contribute to a specific problem. It could help reduce the chance of unsuccessful internships, which could ruin the chances for that company to hire additional interns.

A BIG representative said that it would be helpful to have access to a database where they could post advertisements and people could apply. For that company, an example timeline is that in January the mentor may find out they have a budget for an intern. They then hire in February for a start in June. From February to June they determine the topic and scope of the project. The first question they ask the candidate is "have you talked to your advisor?" If the answer is no, they must put the discussion on hold until the student has talked to the advisor.

One company does an initial training on their campus at the beginning of the internship where the mentor teaches the students to use software. They would like to possibly use a web-based system to inform students how to prepare for internships beforehand, which could save time in this initial phase.

A web-based national network would likely be built on a new platform. Discussions with the MathJobs developers indicates that they would share their experience of developing the existing platform, but that they recommend a different approach for a site to attract industry sponsorship and provide a variety of information types to users.

A job posting bulletin board could

- provide a template for companies to submit openings, and one for mathematical sciences applicants.
- communicate to students the types of technical and non-technical skills desired by BIG institutions.

- provide examples for BIG institutions of how mathematical sciences students are serving in the workforce.
- collect valuable information about internship placements and provide an additional source of internship supply and demand data.
- generate revenue to sustain a national internship network

Discussions with heads of Career Services offices also indicate that the mathematical sciences community could work more closely with them to communicate what kinds of internships are appropriate for mathematical sciences students. This could also help increase the representation of these companies at job fairs.

A mechanism is needed to generate enough internships to satisfy the demand as more students and faculty see BIG career paths as possible and desirable. One participant mentioned that if a company requests students and faculty to work on a particular project and their institution does not have the ability to meet the demand it can be problematic, so a national pool of listings would be very helpful when they need additional faculty/students to satisfy requests.

Marketing and educational communication about the utility of mathematics in BIG environments could greatly expand the number and kinds of opportunities available for students. Participants noted that the professional societies can and should play an important role in this effort. Some materials have been created, but an active role to connect society members within and across societies would help match students and BIG institutions.

Data collection

Developing appropriate training and recruitment targets requires knowledge of the current state of internships. Regular data collection, such as in the Annual Survey of the Mathematical Sciences, would allow us to monitor and measure the impact of new and existing programs. For example, the survey could collect more detailed information in the "Business and Industry" section of New Doctoral Employment. It would be valuable to survey BIG institutions, perhaps through their HR departments and collect data from a mathematical sciences jobs site. The following questions could be a focus of future data collection efforts:

Questions for academic institutions:

- How many PhD students have had some contact with BIG mathematics problems before they graduate?
- How many Master's and PhD students have had BIG internships?
- What types of BIG positions are held by people with degrees in the mathematical sciences?
- How do internships affect the career trajectories of the participants?

- How do faculty view the benefits and costs of internships?

Questions for BIG institutions

- What are the demographics of mathematical sciences people in internships (including level of education)?
- What percentage of internships lead to job offers?
- How does participation in internships vary by education level, area, gender, ethnicity, type of institution, geography, etc?
- How do the supply of internships and demand for internships from students compare?
- What types of BIG positions are held by people with degrees in the mathematical sciences?
- How do internships affect the career trajectories of the participants?
- What could be done to create more BIG internships targeted to mathematical sciences students?

Once there is reliable baseline data on mathematical sciences internships, it will be possible to define success metrics for new internship initiatives. Without the data mentioned above, it was difficult for the groups to provide a detailed plan, but the following goals were suggested:

- Every mathematical sciences PhD student is aware of possible career paths in BIG by the end of their first year.
- 75% of mathematical sciences PhD students have had some contact with BIG mathematics problems in undergraduate or graduate school, through courses, REUs, study groups, workshops, capstones or internships.
- 25-50% of all graduate students have an internship experience. Note that we currently graduate about 1900 PhDs a year, but we may also wish to provide internship experiences for students who finish with a Master's degree. There are also many mathematics undergraduates who will not pursue graduate work in mathematics but may use their mathematics expertise in BIG internships and jobs.

Timing

Participants agreed that students need a variety of timing options. Ideally students would first experience internships as undergraduates or early in their graduate career. But students may choose to refocus their career goals at any stage, and internships can help inform those decisions. Graduate programs should consider when to recommend students pursue internships with respect to coursework, qualifying exams research and thesis writing. One participant cautioned that

although early in the graduate career may seem like good timing from the academic side, corporate funding may be less likely in the 1st-2nd year because students are far from graduation.

Several BIG representatives noted that having an intern requires a lot of time. Preparing the problem requires a non-trivial amount of time even before the supervision begins. Some companies may not have the expertise to do this internally. In this case, one possibility would be to bring the problem to an industrial study group to formulate the problem, then to hand it off to an intern.

A BIG representative who has mentored many interns noted that 3 months is the minimum time for an internship. It takes about 2 weeks to on-board students, figure out the problem, and so forth. After 2 weeks the interns are useful. They work 9AM to 5PM, with many other interns. The work is not like grad school and it is a very good experience. This person meets their interns every day for 10-15 minutes to keep them on track. After 2 months the intern has done exactly what they were asked to do and hopefully more. At the end of 3 months they have to give a presentation. The mentor often has to work to improve the communication skills of the intern. A possible goal is for the work to lead to a patent and a paper, but that does not always happen. The company gets repeat interns year after year, and they prefer the returning interns. When they get returning interns, they try to switch the assigned program or city to expose the student to something totally different. They don't make demarcations between pure and applied math, because the work is all about solving problems.

Another BIG representative said that their company has learned they don't want to wait for the intern to come in before they do all the setup. For example, this year a summer intern came in for a week in March to do all the setup. The company treated the intern as a remote employee from March-May so that the intern was already onboard in May, and it worked out perfectly. The advisor loved it and the student got many skills. They do not have an intern program every year. They ask for an intern only when they know there is a well-tailored program or problem.

Some BIG representatives noted that they have had positive experiences working with outstanding junior and senior undergraduates. They want them as early as possible so that they see positions (such as those at national labs) as career alternatives. When the students are smart and innovative, they will produce results, more and more each year.

An academic participant noted that having students finish their degree on time is not a problem. In that institution, almost all the applied math and computer science PhD students do an internship at some point. Generally they try to have the student write a paper about their work in the internship. Because the culture is established, students talk to other students, and the general understanding is that internships are pretty fun.

Many groups noted that they thought providing broad training to mathematical sciences students should happen as early as possible. The undergraduate curriculum has many opportunities for training in computation, modeling, statistics, algorithms, public speaking and teamwork. Capstones in industrial mathematics and summer internships in BIG institutions can provide mathematics students with a view of career options before they enter graduate school. Much of the career communication that benefits graduate students can also benefit undergraduate majors.

A participant noted that their company approaches recruiting by hiring the best mathematical minds possible, then training for the particular application afterward. Since they may have smaller budgets for recruitment, smaller and medium sized BIG institutions may provide new opportunities for projects and placements.

Recruitment approaches

One participant noted that internship opportunities help academic institutions recruit students into graduate school. This type of approach could increase the number of students in the pipeline for the mathematical sciences.

Recruiting of BIG projects could have several facets. Interactions between faculty and BIG representatives could help identify projects of mutual interest. Communication between BIG managers and staff dedicated to internship development could help identify areas where mathematical science students could be of service in the BIG institution.

- Translate BIG opportunities into mathematical language to help jobs appeal to more kinds of math students.
- Communicate with BIG institutions the kinds of jobs that would be of interest to mathematical sciences students. One BIG representative commented that they were very surprised at the kinds of topics of interest at SIAM conferences. They overlap with the ideas used in the person's group, but the group currently does not employ mathematicians.
- Create a LinkedIn group or set of groups that promote the opportunities and help link interested people to those positions and to each other.

Several participants mentioned equity issues with respect to recruitment. Large BIG institutions have well-established recruiting programs that generally target career fairs at well-known, highly ranked institutions. Top schools have little trouble attracting these companies to recruit at their institution. These local events often include talks, meals, panels and interview opportunities. But these opportunities are not reaching students at all schools and may only be happening in departments (such as computer science and engineering) that have already established strong pipelines to industry. Typical comments included the following: "We don't want the effort just supporting the top universities." Another participant noted "If we

continue with many small efforts, we are not making national movement, we are not making others start things, no visibility."

Improving the number of students from traditionally underrepresented groups who are placed in internships is an extension of the problem of increasing the diversity of individuals in STEM careers. Thus the recommendations in this regard are related to other successful efforts.

- Specific groups like the AWM, Latinos in Mathematical Sciences, SACNAS should interface with "Women in Tech" and other such subgroups within BIG institutions and arrange meetups/talks to disseminate information on non-academic career paths.
- We believe in general that it is important to start earlier (than at the internship stage) to improve diversity. An increase in diversity of backgrounds among graduate students will result in increased diversity of students getting internships
- Mentorship programs can improve the pipeline to BIG jobs. Connect students with a person working in industry with a similar background or interests who is willing to mentor a student.

Funding Mechanisms for Internships

Financial support for internships should take into consideration the costs and benefits to all of the parties involved. BIG institutions that hire interns benefit from connections with new talent and ideas, but also have to expend effort in training and mentorship. Academic institutions benefit from the broad training their students receive in internships, new motivating problems and the possibility of alumni networks in BIG institutions. Students benefit from training, networking, job opportunities and a broader view of mathematics. BIG employees, academics and students all benefit from the intellectual exchange of ideas.

There was strong support for the idea that almost no company would require help to pay for internships. In particular, participants emphasized that in most cases, BIG institutions should pay the whole cost for summer internships. Business and industry do not want external funds because they want control over selection, hiring and intellectual property. A participant from government noted that they are able to cover the cost of internships through various funding mechanisms. Some government labs have at times had more internships than available students, sometimes due to timing and communication issues.

A few academic participants noted that they have had experiences where it was helpful for them to pay a portion of the cost of industrial internships, especially when a company is hiring an intern in the mathematical sciences for the first time. In one example, they paid half of the stipend during the first year and none after

that. Another sent pairs of students and paid half the cost (two for the price of one). Some companies pay the whole cost from the start.

Initially, when appropriate, NSF funds could be used to co-fund the salary and incentivize the company (which would lower the cost to the company, and could provide discretionary funds for the student advisor). After several years of success, co-funding could be reduced. Regular NSF research grants could have a funding policy for student internships.

In addition to the NSF, the participants suggested ideas for government funding including NIH, ONR, DOE, DOD, DARPA, Commerce, Labor, etc, and foundation support such as Sloan, Simons, HHMI and McNair. They noted that if internships focus on strategic priorities, co-funding would be easier to attract. Participants suggested that these efforts should include NGOs and 501c3 organizations.

Other funding ideas included support to reduce the teaching load for faculty interested in working locally to create and support internships. Another idea was that students could be paid for an internship rather than a teaching assistantship, with the same reduced tuition benefits. Some concerns were raised that having the BIG institutions pay for tuition could be too costly unless the student is already planning to enter a specific job and the graduate work is providing training for that job. Such co-op programs happen in departments such as Engineering.

Funding mechanisms for the internship initiatives

A national network could become self-sustaining with sponsorship from industry and/or membership fees. Larger companies have recruiting budgets and are willing to pay a fee to post job advertisements. Smaller and start-up companies may not have the same budget level. There could be naming opportunities for a new network/website.

It is not as clear how regional centers could become self-sustaining. In particular, the staffing could require dedicated and sustained government funding, such as Mitacs is funded. If the regional centers are located at academic institutions, it could be important to make sure the institution has incentive to serve the larger region and not give preferential treatment to their own students.

Local initiatives, such as the one at UIUC, were initially supported with NSF funds for stipends. Once internships were successful, UIUC was able to secure more of the funding from the internship providers. If startup funding for a local effort was provided, then additional funds could be based on success at placing more students in internships over time. To make substantial institutional change, a considerable number of students will need the time and knowledge to participate in internships. In addition to the current Enhanced Doctoral Training (EDT) NSF funding opportunity, are there other ways to motivate this transformation?

Intellectual property

Participants shared a range of possible options for intellectual property (IP) agreements and practices. They agreed that it would be helpful for a set of model agreements to be formulated that could then be tailored to a specific company and university.

Several participants noted that companies would generally prefer to pay for internships so that they will own the IP. One participant noted that paying for interns is necessary to comply with guidelines from the Labor Department. One faculty member had experienced problems when a student used a technique from their thesis research in their internship work. The idea not only became incorporated into the intellectual property of the company, but also the student had signed a non-disclosure so the idea could not be published. Communication about best practices is critical, and representatives advocating for all parties should be involved so that agreements are equitable and communication is clear. A BIG representative noted that their company is sometimes not willing to let employees publish results even after the company has published them, and at times, this has caused them to lose interns. Another BIG representative noted that some companies do allow an intern and faculty member to write a paper about their work after the company has a patent. Others noted that agreements exist that allow ideas to be published in a thesis while giving the company first access to use the IP. Some individuals mentioned that their institutions have information about best practices for IP issues that they would be willing to share.

One participant wondered if it would be possible for students to provide a summary report of their internship work, approved by the company, as an appendix to their thesis, assuming that the student had demonstrated skills relevant to the PhD field. Some suggested the thesis topic should be chosen to avoid IP, export control and classification issues. Others cautioned that students should not do thesis-related work at a company. At the very least, the IP should be agreed upon between company, the student, faculty mentor and the student's home institution. Students and their advisors need information and guidance with regards to non-disclosure and non-compete agreements. It would be helpful to provide this information to the mathematical sciences community at a national level.

TRAINING

Building Student Skills that Complement the Mathematical Sciences

While students can begin to learn skills in intensive workshops, they need to be reinforced over time as part of the regular undergraduate and graduate experience in the mathematical sciences. These skills will help Mathematical Sciences professionals advance in their careers, obtain influential positions, and mentor others. Note that the problems students tackle need to be more than toys to prepare students for the workplace.

Programming as a means of concrete implementation of mathematical ideas. Typical programming environments include Python, C++, R, Perl and others. Students need familiarity with efficient algorithms for problem classes, version control, code collaboration, cloud computing. Students should be comfortable with Linux and using higher-level programs such as Matlab or Mathematica for prototyping. Students with some proficiency can learn from websites with free coding training/problems including Coursera, edX, Hacker Rank, MIT Open Courseware, Project Euler, Software Carpentry and Udacity. Because programming is often the barrier to mathematics students in industry, it needs to be emphasized more at the undergraduate level.

Data science such as statistical methods, machine learning, queries and image processing. Students need to be able to apply current methods to organize and analyze data, including large datasets and data structures. Actual experience with data (including data preparation, handling and storage) should be emphasized in addition to theory and methods.

Modeling and simulation,which includes formulating models, optimization and implementing systems for comparison with data. Modeling problems can help students practice flexible and adaptable problem solving.

Communications and "soft skills" training is an integral part of any internship, and students are expected to bring proficiency in these areas to the job. The individual and problem-set/exam oriented nature of mathematical sciences programs can mean that students have not spent academic time on these critical skills. Some soft skills training materials are available online, but others require individualized feedback and might be best sought at home institutions.

- Presentations: technical, data visualization, writing, for interdisciplinary or general non-technical audiences, concision, clarity, analogies
- Interpersonal/Interview skills: problem solving, and elevator pitches, asking good questions.
- Teamwork: experience with collaborative work on projects, empathy, listening, giving and accepting feedback constructively
- Leadership experience: project design and management, budgeting, meeting facilitation, mentoring undergraduates, persuasion.
- Initiative – independent study, extracurricular learning/research

Faculty Professional Development

Faculty and departments need to be made aware of the value of internships to students and of the depth and sophistication of the work carried out during them. A central organization could play a role in providing professional development for faculty. In order to reach as many graduate students as possible, we could convene

Directors of Graduate Study (at JMM, say) to provide practical "starter steps" that participants can implement immediately to improve their students' preparation for BIG careers. This is an area where the Professional Societies and the Mathematical Sciences Institutes can play a substantial role.

As part of the comprehensive marketing strategy, we also imagine creating materials to train faculty to make connections with local BIG institutions. This would include information about how to promote mathematical sciences students as skillful team members; success stories of math interns in BIG positions; and possibly webinars or workshops about how to approach companies, how to make cold calls, and how to organize a local one-day workshop to showcase what is happening in local industries and how math students might contribute. The local one-day workshops would not require substantial financial support, as they should include largely local speakers.

The PIC Math Program (Preparation for Industrial Careers in Mathematics) has a one-week workshop to train mathematical sciences faculty to engage with BIG institutions and create undergraduate courses. The materials from this program, including the videos in Appendix E could be adapted for wider future use.

There remains an open question of how to align incentives to encourage faculty support of and participation in these activities. With a Center demonstrating national support for this project, Deans might be convinced to grant teaching release or small stipends to compensate faculty who spend significant time developing ties to local BIG institutions. Development and Alumni offices can be enthusiastic about forging connections with local institutions. Local university research parks may also provide ``low-hanging fruit" for forging connections.

MAKING A POSITIVE CASE FOR INTERNSHIPS

We have a critical workforce issue at hand: the number of PhDs produced each year in the mathematical sciences outnumbers the tenure-track positions available. In addition, many students trained in the mathematical sciences would like to enter BIG jobs after their undergraduate or master's degree. Some business, industry and government institutions recognize the value of computationally savvy students trained in the mathematical sciences. Some do not recognize that mathematical sciences students have as much to offer as students trained in engineering or computer science. If we are to place mathematical sciences students in BIG, academic institutions need help by adapting or supplementing their programs to help their students train for BIG jobs and we need to communicate that these students are ready and able to make important contributions.

One working group focused on cultural issues that could be addressed to improve attitudes towards BIG jobs, especially for graduate students with advisors unfamiliar with the types of mathematical problems addressed in business, industry and government. As mathematical sciences community in the US increases its

partnerships with BIG, we can showcase internship success stories and communicate the benefit internships provide to everyone involved.

As we communicate the positive impact of internships on the workforce, participants emphasized that though we need to highlight connections between areas of mathematics thought of as "pure" and BIG, that we should not use the label "pure." This polarizing distinction between areas of mathematics is not necessary and may in fact work against the goal of encouraging people to see the mathematical sciences as a whole as valuable and relevant in both academia and BIG. Several opportunities for communication and outreach are listed below:

- Create and display posters in departments that correspond branches of mathematics with BIG innovations.
- Create a central website with success stories, data, videos, including "Faces of Math in Industry."
- Invite local industry and alumni to campus; could be hosted by local student chapter(s)
- Publish papers in AMS Notices, American Statistician, SIAM Review about why internships are important and valuable – include data and anecdotes.
- Write regular features in society newsletters (SIAM, AMS, AWM, AMSTAT News, MAA Focus)
- Organize online webinars and chat room discussions about BIG careers
- Organize workshops, panels and talks at conferences
- Communicate stories about math in BIG using social media
- Create and disseminate short videos (see examples in Appendix E)

New forms of recognition and incentives

Participants noted that department leadership (especially chairs and directors of graduate programs) can impact attitudes by stating loudly and often that they expect graduate students to prepare for BIG careers. Several workshop participants will engage these groups at the Joint Mathematics Meetings to discuss these ideas. Societies can also help communicate these ideas with current and future leadership. In addition, practical, visible steps such as a careers email listserv can communicate to the students that it is OK to show interest in non-academic careers. Participants emphasized that the skills developed in BIG internships can benefit students who choose to stay in academia, regardless of area. First, many of the skills gained in internships are transferable to academic research. Second, familiarity with internships will help them advise future students about career options. Here are some additional ideas that can make a positive case for internships:

- Invited talks at conferences and in departmental symposia
- Community recognition through societal awards, including mentoring awards, student awards (via poster sessions)
- Incentives such as summer salary, teaching or service credit for co-mentoring BIG projects

- Industrial research recognition in reevaluation, promotion and tenure
- New metrics for departmental reviews and rankings
- Positive communication about non-academic careers as an option for all students
- Inclusion of industry and government jobs in genealogy projects
- Hiring of faculty with industry perspective
- Multifactor metrics for student success (startup, patents, etc), even without PhD completion.
- Metrics to assess the value of non-published work carried out during internship, such as a summary report approved by the company appended to thesis.

What mathematical sciences students bring to BIG

Mathematical scientists bring the ability to work independently, new types of innovation, and a deep understanding of mathematical and statistical modeling. The fields bring a diverse pool of applicants. For example Statistics has gender balance and strong numbers of students from traditionally underrepresented groups. Students trained in the mathematical sciences and prepared for internships:

- abstract practical problems using a mathematical framework
- solve problems that are not concisely formulated
- bring new tools to BIG problems
- adapt to new types of problems and learn new theory quickly
- contribute advanced quantitative skills
- focus on reasoning underlying process or procedures
- communicate well in or outside of their discipline

Benefits of internships for mathematical sciences students

Internships enrich graduate study by providing context for academic research, as well as by training students to communicate with a range of different people. Both hard and soft skills gained in internships enhance the professional development of graduate students.

In internships, mathematical sciences students:

- learn practical skills to solve real problems
- solve real problems in business, industry and government
- conduct interdisciplinary research
- gain new career paths

After completing an internship, students will bring a broader view of the role and impact of the mathematical sciences to their next position, whether in academia, BIG or other fields. Disseminating this perspective will benefit future students entering the national workforce.

CONCLUSIONS

The mathematical sciences community has many constituents who are ready to embrace internships and BIG career paths. The time is right because there is both demand in the BIG job market and a need to place mathematical sciences PhDs in desirable jobs. To build these opportunities, we must communicate how computationally trained mathematical sciences students enhance the workforce. We must highlight skills that are different from and complementary to those brought by computer scientists and engineers, who have a stronger and well-established tradition of internships. If new internship initiatives are to have significant national impact, we must build on the substantial expertise within the mathematical sciences community and broaden the base of this expertise.

Workshop recommendations:

The workshop recommendations can be summarized in a call for

- Infrastructure at the national, regional and local levels
- National networking to share best practices and solutions to logistical issues such as timing, intellectual property, and funding
- Data collection about internship supply and demand
- Multi-faceted training opportunities
- Initiatives that make the positive case for internships

Final comments from the participants can be found in Appendix D, which emphasizes unanimous appreciation for the time to discuss these ideas. Representatives from all constituencies have expressed strong interest in working together to improve future internship opportunities and career paths for the mathematical sciences.

Acknowledgements

The organizers would like to thank the NSF for initiating and funding this conference. We would like to thank the staff of IPAM for their support of the workshop. Finally we would like to thank the reviewers of this report for their insightful comments and suggestions.

Appendix A: Participant List

Alejandro	Adem	Mitacs
Jorge	Balbas	Institute for Pure and Applied Mathematics
Paul	Bendich	Duke University
Vijay	Bharadwaj	Netflix
Rich	Braun	University of Delaware
Allen	Butler	Daniel H. Wagner Associates
Russel	Caflisch	University of California, Los Angeles (UCLA)
Linda	Cummings	New Jersey Institute of Technology
Natalie	Durgin	Spiceworks
Karina	Edmonds	California Institute of Technology
Katherine	Ensor	Rice University
Sujit	Ghosh	North Carolina State University
Frank	Graziani	Lawrence Livermore National Laboratory
Mark	Green	Institute for Pure and Applied Mathematics
Tara	Holm	Cornell University
Nandini	Kannan	National Science Foundation
Bruce	Kitchens	National Science Foundation
Rick	Laugesen	University of Illinois at Urbana-Champaign
Kristin	Lauter	Microsoft Research
Emille	Lawrence	University of San Francisco
Alan	Lee	AMD
Rachel	Levy	Harvey Mudd College
Reza	Malek-Madani	Office of Naval Research
Bani	Mallick	Texas A&M University - College Station
Esmond	Ng	Lawrence Berkeley National Laboratory
Stan	Osher	Institute for Pure and Applied Mathematics
Sastry	Pantula	Oregon State University
Ami	Radunskaya	Pomona College
Christian	Ratsch	Institute for Pure and Applied Mathematics
Jim	Rosenberger	Pennsylvania State University
Richard	Ross	HRL Laboratories, LLC
Fadil	Santosa	Institute for Mathematics and its Applications
Susana	Serna	Autonomous University of Barcelona
Luis	Serrano	Google
Joseph	Teran	UCLA
Eric	Vance	Virginia Polytechnic Institute and State University
Lalitha	Venkataramanan	Schlumberger-Doll Research
Bogdan	Vernescu	Worcester Polytechnic Institute
Michael	Vogelius	National Science Foundation
Henry	Warchall	National Science Foundation
Robin	Wilson	Cal Poly Pomona
Tom	Witelski	Duke University

Appendix B: Workshop Agenda

Tuesday September 1, 2015

As people arrive, view slides with info about participants.

8:00-9:00 Breakfast
9:00-9:10 Welcome, Russ Caflisch, IPAM
9:10-9:45 Presentation + Q&A, Henry Warchall, NSF
10:00–10:15 Conference overview, Rachel Levy, Harvey Mudd College
10:15-11:00 Charrette with refreshments
11:00-11:45 Presentation + Q&A, Alejandro Adem, MITACS
11:45-12:15 Presentation + Q&A, Rick Laugesen (UIUC)
12:15- 1:15 Lunch (Option to add more sticky notes)
1:15-2:00 Whole group discussion: critical issues, aha moments, resonance
2:00-3:00 Primary writing group discussions /notetaking
3:00-3:15 Break
3:15-3:45 Rotation 1 sharing/discussion/ notetaking
3:45-4:30 Rotation 2 sharing/discussion/ notetaking
4:30-4:45 Break
4:45-5:45 Small writing group session – draft big ideas to address questions
6:15- 7:30 Photo and Conference dinner

Wednesday September 2, 2015

8:00-9:00 Breakfast
9:00-10:15 Gather then continue writing session, prepare presentations
10:15-10:30 Break
10:30-11:45 Report out
5 minute presentation, 2 minutes for written comments and 8 minutes discussion
10:30 – 10:45: Support
10:45 – 11:00: Recruiting
11:00 – 11:15: Logistics
11:15 – 11:30: Training
11:30 – 11:45: Culture
11:45- 12:00 Closing
12:00 - 1:00 Lunch

Appendix C: Models of existing internship programs

Mitacs Presentation

Alejandro Adem from MITACS (Mathematics of Information Technology and Complex Systems) gave a presentation to the whole group. Mitacs is an independent, not-for-profit research organization governed by Canada's research universities. Motivations for the program included poor funding levels for mathematics in Canada, math PhDs leaving Canada & graduate studies enrollment declining, and a sense that perhaps industry needed mathematicians and would fund research.

In 1999 there was a proposal for a Network of Centres of Excellence of Canada (NCE) with 100 companies, $1M in commitments and 200 Canadian mathematicians. [[was this a call for proposals or THE MITACS proposal?]]. Three key allies were identified as The Fields Institute, The Centre de Recherches Mathématiques (CRM) and the Pacific Institute for the Mathematical Sciences (PIMS). In 2000 there were 21 projects launched with Dr. Arvind Gupta as the Scientific Director. Since then there have been large increases in governmental funding and participation from other disciplines. Mitacs now supports more than 3,500 research projects annually with 130 staff, 30 offices and hubs in Vancouver, Toronto, and Montreal. However, the number of projects in the mathematical sciences has not grown much over time.

The key ingredients to the Mitacs model are relevant, flexible programming, research integrity, a partnership approach between universities, government, and industry, proactive business development and demand-driven innovation. Programs include

Accelerate – graduate research internship program with co-supervision between academic and BIG partners, professional skills development, cost-sharing and a platform for technology transfer and commercialization.
Elevate – R&D Management training for postdocs
Globalink – international research mobility with inbound and outbound streams with partners in Brazil, China, France, India, Mexico, Saudi Arabia, & Tunisia
Step – professional skills training program. In 2014-15 this program provided 278 workshops in presentation skills, R&D management, business writing and financial literacy.

Mitacs has a Research Council (MRC) to provide scientific leadership, oversee research integrity, with subcommittees to establish the scientific vision and goals, develop and oversee research adjudication processes and provide recommendations on programs and initiatives. The partnership with universities and research institutions is at the core of Mitacs. Additional partners include the Natural Sciences and Engineering Research Council (NSERC), Social Sciences and Humanities Research Council (SSHRC), Genome Canada and Industrial partners

(who enter multi-year internship agreements).

MITACS employs a team structure for business development. Business development (BD) staff includes:

- Account Managers: The most senior BDs who work with large industry clients handling major accounts; research demands
- Directors: Masters or PhDs who also have industry experience. They work approximately 50% of the time with professors and 50% with companies.
- Specialists: Recent PhD graduates whose experience is primarily academic and who spend most of their time working at universities.
- Co-funded BDs: A win-win situation for university partner and Mitacs. The university receives a dedicated BD specialist, solely focused on the needs of that university. Salary paid 50:50 by Mitacs and the university.

Adem closed his talk with some suggestions. He recommended that any new program should fit within the current policy context. He advised that we engage early champions from a broad range of stakeholder groups to get buy-in and help with promotion. We should identify clear expected outcomes & impacts *a priori* and develop an evaluation strategy/performance measurement framework to ensure a plan to get there. Finally we should stay relevant by being innovative thought leaders in the space. More information at https://www.mitacs.ca/en.

University of Illinois at Urbana-Champaign Presentation

Richard Laugesen from the Department of Mathematics at the University of Illinois at Urbana-Champaign (UIUC) shared a set of successful initiatives that have increased the number of internships in his department, which has not traditionally focused on industrial mathematics. At UIUC the mathematics department has72 faculty, 25 postdocs, and 15 lecturers. They have 160 PhD students, 40 Masters students and teach 24,000 undergrad student-courses per year. They graduate 20-27 PhDs each year and have no separate applied mathematics program.

The Mathematics PhD students are half U.S., half international, mostly from public undergrad institutions, 60 women and 100 men. About half have coding skills consisting of undergraduate computer science courses or a minor in CS. Few have an "applied mathematics" background.

To communicate with their students about possible career paths, UIUC has implemented

- Career panels and round-tables
- Advice and résumé critiquing by career center
- BIG careers listserv for grad students
- Networking with BIG employers and scientists on campus
- NSF workforce grant "PI4" (precursor to EDT)

- Computational Mathematics Bootcamp

Host type	2013	2014	2015
On-campus corporate	2	6	10
Off-campus corporate	3	2	6
Government	1	3	4
On-campus scientific labs	0	6	7
TOTAL	**6**	**17**	**27**

Table 1: Growth in BIG Internships at UIUC

Intern demographics	2013	2014	2015
Women/Men	1/5	8/9	13/14
Domestic/International	3/3	13/4	18/9
Early/Middle/Late/Masters	0/1/5/0	9/3/5/0	8/9/6/4
Applied/Pure	4/2	8/9	9/18

Table 2: Demographics of BIG Math Internships at UIUC

At UIUC, several students who might not think of their thesis focus as applied or industrial mathematics topics have participated in internships, sometimes through on-campus collaborations with lab groups in other departments. For example, a combinatorist modeled infectious disease in sheep, in a veterinary medicine lab. A number theorist modeled ant colonies, in the entomology department. A functional analyst worked with an e-commerce analytics firm. A graph theorist worked with a financial trading firm and a student interested in differential equations worked on agricultural data analytics. One helpful mechanism for placing students in the internships is interviewing them about their interests outside of mathematics.

Funding for some of the internships was provided by an NSF grant: Program for Interdisciplinary and Industrial Internships at Illinois (PI4). The program has included topics courses during the academic year such as "Top 10 Algorithms of 20th and 21st Century." Each summer begins with a two-week Computational Mathematics Bootcamp that covers shell scripting, Python, Matlab, and Fenics. Then the 0th and 1st year students (12 funded students) continue with a 6 week exploratory mathematics group, while more senior students go to BIG internships (5 funded industrial interns, 7 funded scientific interns). Another 15 PhD students arranged their own summer internships in 2015, independently of the PI4 program.

The goals of the program support BIG career exploration by placing "pure math" students first into scientific internships, and later to corporate or national labs. If possible the program places interns in *pairs.* Corporate hosts are incentivized through cost-share ("buy one, get one free") and PI4 stipends are often topped up by the corporate hosts (because the hosts *want* interns to be employees). The grant provides a stipend for the exploratory math group leader and for program organizers. The non-PI4 interns find their own hosts through UIUC connections or applying directly online.

Corporate intern hosts have included a regional utility company (data analytics), boutique agricultural data analytics firm, energy multinational (biofuels research), agricultural/chemicals multinational, image recognition start-up and agricultural machinery multinational (modeling and data analytics).

Future plans for the program involve more in-semester computational training (workshops and short courses), more students working with faculty in other disciplines, more hosts, especially off-campus, and more faculty involved. For further information on PI4 see https://pi4.math.illinois.edu. The principal Investigators are Yuliy Baryshnikov (Mathematics and ECE), R. Lee DeVille (Mathematics) and Richard Laugesen (Mathematics, Director of Graduate Studies).

Appendix D: Final comments about the workshop from participants

- The workshop was well organized and the ideas generated will be very helpful at my institution. I would definitely like to attend a similar workshop again.
- The charette and break out groups worked incredibly well.
- I feel much better informed at this point, about how to advise my students (undergrad and grad).
- I learned about the diversity of industry perspectives.
- It was worth a day and a half if NSF does use the recommendations of the conference.
- Workshop was preaching to the choir but very valuable impact in the mathematics community if we implement/develop the ideas discussed here.
- Great job! Being a physicist involved in recruiting, this workshop helped a great deal in opening my eyes to (a) issues facing mathematics (b) similarity in the issues mathematic and physics have (c) The need to reach out to the math community.
- Very useful ideas to share back with departments. Ability to say that there are widespread interests and agreed on views in the community is very helpful in trying to get movement.
- The value for me was meeting new people. Interacting with mathematicians and seeing how early statistics can be overshadowed by math. Giving me time outside my normal work to think about things. When I am removed from my typical environment I tend to get new ideas applicable to my work.
- An important national question has been posed. I was pleased to provide input through my participation.
- Tremendously valuable to connect with others around the country who are tackling the same issues! (I had only met a handful of other participants previously.)
- Workshop was very well organized!!
- Value: New contacts with people from industry who are receptive to math and what it offers. Opportunity to talk to program managers and (maybe) influence policy.
- I enjoyed the workshop a lot; learned new things about culture in the math community.
- EDT can still be useful in addition to BIG internships to foster interdisciplinary training that is not necessarily BIG. But, such PhDs would be of more interest to BIG than standard math training.
- The Dept of Commerce would naturally fund small to medium size companies to have interns, not fund students.
- Great to hear what others are doing, which gave me ideas of things to do and inspiration.
- I learned a bit more about what industry wants to do with internships and how they do it.

- It was valuable to learn how much less connected the academic mathematics community is with industry. It was also revealing to learn that job wording could discourage potential candidates from applying.
- The format was very well thought out!!
- This was very valuable as a networking opportunity and to meet some very smart people thinking about an important societal issue.
- Valuable time – Overcame my cynicism about the practicality of these projected culture changes.
- This workshop was valuable to understand the points of agreement, as well as some disagreement, on the importance of this endeavor.
- MITACS has been largely unsuccessful at engaging with math. It's important to learn from that.
- Very nice workshop! I learned enormous amount of what other unis are doing and also more about industry timelines.
- Great organization! After being in academia and industry, it is very nice to see more of what lies between, and to have the chance to explore/strengthen the bridges between them. This was a great use of my time, thank you very much!
- I get interns every year. It would be very helpful to me if the process of screening interns and recruiting them was more streamlined.
- We need to invite more companies to the table. Bring high-level people in BIG to the table. Without them at the table none of these efforts will be sustainable. Some of the BIG companies don't see the need for our help since they are getting the cream of the crop. It is the volume of talent that we are leaving behind that is a concern.
- Departments have the tendency to hire their own grads to teach the volume of courses cheaply on campus. This culture needs to change.

Appendix E: Examples of existing programs and resources

Videos

- Landscapes of Capital Video: Smarter Math Smarter Planet
  http://landscapesofcapital.com/items/show/900

- IBM Video: A Smarter Planet Relies on Data Analysis
  https://www.youtube.com/watch?v=CxQHwmhJXX4

- IBM Video: Smarter Food - United States
  http://www.ibm.com/smarterplanet/us/en/food_technology/article/food_technology.html

- Pic Math Video: Improving Marketing Strategies
  Dr. Jonathan Adler**:**https://www.youtube.com/watch?t=1&v=1Csmp_KWMjY
  Prof. Talithia Williams**:** https://www.youtube.com/watch?v=jhQkfbitYk4

- Pic Math Video: Creating More Realistic Animation for Movies
  Dr. Alex McAdams: https://www.youtube.com/watch?v=z8wlEsSnpQY
  Prof. Joseph Teran: https://www.youtube.com/watch?v=TwHiZvLz1mA

- Pic Math Video: Building a Better Filter
  Dr. Sumanth Swaminathan:
  https://www.youtube.com/watch?v=uU5wGm5kQnU
  Prof. Louis Rossi: https://www.youtube.com/watch?v=ZWzOsOHBjBQ

- Pic Math Video: Finding the Safest Place to Store Nuclear Waste
  Dr. Genetha Gray **https://www.youtube.com/watch?v=yLzd7djTeg8**
  Prof. Gwen Spencer https://www.youtube.com/watch?v=RYF9vBrLi4Q

Organizations

- University-Industry Demonstration Partnership
  https://www.uidp.org/
- Smith Institute in England
  http://www.maths-in-industry.org/
- European Consortium for Mathematics in Industry (ECMI)
  http://www.ecmi-indmath.org/
- Maths in Industry Case Studies (associated with the Fields Institute)
  http://www.micsjournal.com/
- APS Forum on Industrial & Applied Physics
- Mathematics-in-Industry New Zealand (MINZ)
  http://www.minz.org.nz/
- IEEE Collaborative R&D Projects
  http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=917332&url=http%

3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D917332

Publications

- IMA Volumes Mathematics in Industrial Problems edited by Avner Friedman http://www.ima.umn.edu/springer/volumes.html
- Journal of Mathematics in Industry http://www.springer.com/mathematics/applications/journal/13362
- SIAM Regional Meetings and Report on Mathematics in Industry http://www.siam.org/reports/mii/1996/index.php http://www.siam.org/reports/mii/2012/
- SIAM Careers in Mathematics http://www.siam.org/careers/thinking/pdf/brochure.pdf

Web Resources

- Who Employs Mathematicians? http://www.mathscareers.org.uk/article/who-employs-mathematicians/
- Where do maths graduates actually work? http://www.mathscareers.org.uk/article/where-do-maths-graduates-actually-work/
- See AmStat news for articles on BIG careers with pictures, posters, and respect for these professional careers. Such articles do help grad students think about BIG careers.

Fellowships/Training/Graduate Programs

- UIUC and Mitacs (see above)
- MSc in Industrial Mathematical Modeling (Loughborough University) http://www.lboro.ac.uk/study/postgraduate/programmes/departments/mathematics/industrial-maths-modelling/
- University of San Francisco https://www.usfca.edu/arts-sciences/undergraduate-programs/data-science
- Brigham Young University https://math.byu.edu/degreeprograms/careersinternships/
- Oxford Centre for Collaborative Applied Mathematics (OCCAM) http://www0.maths.ox.ac.uk/groups/occam
- University of Delaware http://www.mathsci.udel.edu/research/research-areas/Pages/industrial-and-applied-mathematics.aspx
- Harvey Mudd College https://www.hmc.edu/clinic/
- North Carolina State University https://www.math.ncsu.edu/REU/

- Insight Data Science Fellowship
  http://insightdatascience.com/
- WPI REU Program in Industrial Mathematics and Statistics
  http://www.wpi.edu/+CIMS/REU
- Research in Industrial Projects for Students (RIPS) at IPAM
  http://www.ipam.ucla.edu/programs/student-research-programs/research-industrial-projects-students-rips-2015/
- Math Problems in Industry (MPI) http://www.math.wpi.edu/MPI/
  (Effort of RPI, UDel, WPI, and NJIT via NSF)
- Graduate Student Mathematical Modeling Camp
  (NSF-supported in conjunction with MPI above)
  http://homepages.rpi.edu/~schwed/Workshop/GSMMCamp2014/home.html

Appendix F: Motivating questions provided to working groups

Support

- How can academic institutions support internships?
- How can advisors support internships?
- How should the internships be supported by sources external to academic institutions?
- What are the best ways to incentivize companies to create more mathematical internships?
- What do mathematical sciences students bring to the table? How can we better communicate our skills to companies?
- What type of staff positions might be necessary to create more internship opportunities?
- Who should do the administrating, recruiting and organization of internships?
- Who should do troubleshooting, problem solving and contact management?
- Who should evaluate which of these ideas are working?

Recruiting

- How do we connect a diverse group of students to internships that work for them?
- What are the best ways to advertise internships?
- The top students at top institutions are being recruited. How do we create recruiting opportunities for students from a variety of institutions and with various preparation levels?
- How can we help companies meet their diversity goals for their workforce?
- How can we encourage people who were trained in math and are already in industry to help recruit and share their experiences?
- Are there internships types or topics that are inappropriate for mathematical sciences students?
- How can we facilitate/increase recruitment from small, medium and large companies and governmental labs/institutions?
- What features of an internship inform the recruiting process?

Logistics

- Who should own the intellectual property developed in an internship?
- What proportion of mathematical sciences students should we target for internships?
- Who should pay for internships? Who should be paid? What is realistic to expect?
- When is the best time in graduate school to have an internship?
- What duration of internship makes sense?
- Should the internship infrastructure occur in a centralized organization?

- How much internship organization should happen through academic departments?
- What issues may arise for students when they work on proprietary projects?
- Could it be problematic for federal funding agencies to endorse particular internships?
- How should liability be handled?
- How should publication/dissemination of results be handled?
- Could a center for internships ever become self-sustaining?

Training

- What is the best way to help students navigate an MA or PhD successfully while engaging in an internship? Assume you want to prepare students for academic or non-academic careers.
- What can/should the role of a PhD advisor be in their student's internship?
- What courses available in academic institutions will best prepare mathematical sciences students for internships?
- What skills might need to be provided in intensive training camps?
- In what ways do pure math, applied math and statistics grad students have different needs?
- What can be done within regular programs to prepare students for careers in industry and government?
- How much coding training should math students receive?
- What kinds of soft skills training should math students receive?
- What are the risks of increased student/faculty engagement in internships?

Culture

- How do you address the concern that an internship is a waste of a PhD student's time?
- How do you address the concern that an internship will distract PhD students from more important efforts or split their attention in a way that has negative consequences?
- How can we help faculty see industry as a great possible option for any student rather than an alternative for weaker students?
- How do internships benefit students who may pursue academic jobs?
- How do internships benefit faculty?
- Is it OK if an internship makes completion of a PhD program take longer?
- Can it be seen as a positive outcome if a student leaves a PhD program early to take a position in industry/government?
- How do academic cultural issues affect pure and applied students differently?
- Will students worry that this preparation will box them into a career path and take away future academic possibilities?
- How might this training impact the student-advisor relationship?
- If an internship leads to a lower publication rate, how might this affect the person later on the academic job market?

Appendix G: NSF-IPAM workshop writing group tasks

Please organize and synthesize the ideas generated in your group into a coherent communication. If possible, answer the questions posed to the group, or explain why they cannot be answered at this time. Don't worry about length or formatting for now.

Our broad goal is to explain how to improve the jobs pipeline and workforce capacity in the mathematical sciences by increasing the number of internship experiences. Our suggestions should facilitate awareness of and access to internship experiences (for business, industry and government (BIG) institutions, faculty and students). Proposed programs should be designed to broaden participation and sustain work in the mathematical sciences.

Our starting writing groups are **support, recruiting, logistics, training and culture.** Your group may choose to tackle additional topics once they have answered the originally posed questions. The critical considerations handout has additional topics and questions for the report that may be of interest to the group.

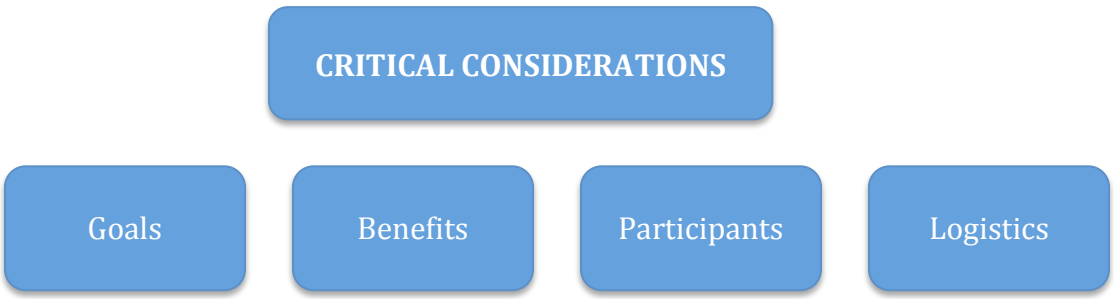
As you consider national infrastructure that can support internships, please discuss the pros and cons of the following organizational/delivery models with respect to your topic:

- Virtual (online) programs and services
- Centralized coordinating institute
- Decentralized programs at academic institutions
- Decentralized programs in business, industry and government institutions

You may decide a particular model will best address an issue raised in your group, or you may suggest that a combination of models would be most effective. Ideas from all of the groups will be combined into a single report, commissioned by the NSF. This report may be of interest to a wide audience, including faculty, industry representatives, directors and staff of internship programs, and funding agencies as well as interns. Please upload your writing, along with your scribe's (and any other) notes from your conversations to the Google docs folder with the name of your group.

Appendix H: Mathematical Sciences Internships: Critical Considerations
Rachel Levy, Harvey Mudd College

This document outlines critical considerations for an NSF-IPAM workshop Sept 1-2, 2015 to consider whether a U.S. national center for business industry and government (BIG) internships, perhaps similar to the MITACS program in Canada (www.mitacs.ca/en), should be created. The answers to the following questions will help determine how to structure national initiatives to provide more opportunities for internships. Four critical considerations, subtopics and questions provide a starting point for conversation. **This document represents a possible structure for the final report. We ask workshop participants to review this document before the workshop, since the organization/questions are structures for the report and are not the same as the writing group topics. Some of the questions here should be considered across all of the writing groups.** We will adjust the structure and content of the report based on feedback from the workshop.



Goals

What are national goals should we have regarding mathematical sciences internships?

- To increase the number of mathematical sciences students in internships
- To increase the number of internships in the mathematical sciences
- To increase the visibility/awareness of BIG job opportunities
- To promote BIG jobs as viable and desirable career options
- To provide alternatives to academic jobs
- To create new partnerships between academia and BIG institutions
- To increase the number of courses offered to mathematical sciences students in skills that would be valuable for BIG careers
- To guide students about what courses they should take and skills they should acquire if they want to pursue BIG careers
- To prepare more students from the mathematical sciences to make significant contributions in BIG careers

- To communicate with small, medium and/or large companies about the value of hiring mathematical sciences students and graduates.
- To help individual faculty make new contacts in industry and begin collaborations and/or create opportunities for their students
- To facilitate the matching process between students and internships
- To pay for or share the cost of internships
- To cross train pure mathematics students (and more generally, students seeking academic positions) so that they are aware of and are more prepared for a variety of career options
- To help students undecided about their career path get a taste of BIG jobs (since they already see models of the academic life during schooling)

What models of existing internship programs should be considered?

- MITACS in Canada
- Consortium such as the Smith Institute in the EU
- BIG Math "bootcamps" for students
- Targeted recruitment of internships by staff and/or faculty
- Programs at specific academic institutions
- National (physical/virtual) center for BIG Math internships
- Web portal with internship information / matching / education
- Decentralized programs at many institutions
- Financial incentives for companies

Benefits

What are the potential benefits to students?

- Provides experiential learning about BIG math work environments and role models outside of academia
- Can motivate more study of mathematics or a particular focus
- Could provide viable career path for Masters students not interested in PhD and for PhD students (who are preferred by many companies)
- Internship could potentially pay better than a Teaching Assistantship
- Could provide a change of pace from academics (and help prevent burnout)

What are the potential benefits to academic institutions when their students participate in internships?

- New collaborations and interesting problems for faculty
- More possibilities for employment for graduates
- Connections with alumni in both academic and BIG jobs
- Financial support for students
- Motivation for new courses

What are the potential benefits for BIG institutions?

- Recruitment
- Possibility of solving high risk high reward problems off the critical path
- Long term interview of potential recruits
- New collaborations with academia
- Potential to increase diversity of workforce
- Rewarding mentoring experiences for employees
- Innovation
- Lower cost workers
- Are there also potential risks or negative factors?

Participants

Which students should participate in the program?

- Undergraduate/Graduate Students/Postdocs
- Students with particular academic backgrounds
- Particular disciplines within the mathematical sciences
- Top students/All students
- Students from large/small, public/private, research/liberal arts institutions
- Students whose advisors are interested in industrial problems
- Students aiming for academic/BIG jobs or are undecided

What types of institutions should provide the internships?

- Big/medium/small companies – how are their needs/structures different?
- Companies that already/do not already employ mathematicians
- Companies in major cities/ smaller cities
- Companies near academic institutions with mathematical sciences programs
- Government labs/programs
- Companies with/without existing internship programs

What preparation would students need, and who should provide it?

- Focus deeply on at least one area of the mathematical sciences
- Become familiar with the math and technical knowledge needed on the job
- Study computing/programming (level depends on the job)
- Study data science / statistics
- Demonstrate ability and inclination to follow through on assignments
- Develop curiosity, perseverance, creativity
- Gain softs skills (such as project management, organization, communication, documentation, teamwork)

How can students become more aware of BIG Math Internships and Jobs?

- Presentations from mathematical scientists in BIG jobs
- Participation in BIG math training programs
- Visits to BIG math institutions
- Class assignments with connections to industry
- Mathematical modeling competitions
- Math in industry workshops and study groups
- Career fairs
- Talks by BIG Math representatives (at conferences or academic sites)
- Online resources (websites, job portals, video)
- Undergraduate summer and capstone experiences
- Short or long term internships

Logistics

What features of an internship inform the matching process?

- Topic (job may not be called mathematics)
- Geographical location (transportation, housing)
- Duration
- Pay structure
- Mentoring
- Applicant skills/experience

What are important logistical/legal considerations?

- What times in a student's progress are best for internships?
- How long should the internships last?
- Who should provide the funding for internships?
- How should intellectual property (IP) be handled?
- How should publication/dissemination of results be handled?
- How should liability be handled?
- What should the matching process be and who should do the matching (company/center/academic institution)?

What might be some potential impediments to internships?

- Time in an internship could be viewed as a distraction from PhD work.
- If student chooses not to complete a degree to take a position, the outcome could be viewed as a failure. Could this perspective change?
- Publication rate might be lower for students/postdocs in BIG internships
- Students might not be able to stay in internship long enough to be of value to the company or to gain insight about the range of possible jobs.

- Companies might not know how mathematics students (and their faculty mentors) can be of value.
- Without the advisor's support, an internship could cause friction during the degree-seeking process.

What are the potential costs involved in an internship center?

- Headquarters (costs associated with a building and computing)
- Salary of directors and other staff (such as IT and HR)
- Salary/stipends for internship recruiters around the country
- Travel for recruitment, retention of projects
- Student support during internships (salary, travel, room/board)
- Cost of supporting faculty in collaboration/mentoring positions
- Training programs for students and/or faculty
- Website to assist with matching process
- Legal assistance with agreements and intellectual property issues
- Could a center ever become self-sustaining?

Appendix I: Example internship resources listed for students at the University of California, Berkeley:
Source: https://career.berkeley.edu/Internships/IntCurrent

- Bay Area Volunteer Information Center - Lists Bay Area nonprofit organizations that need volunteers to support their services. Sometimes the best way to get experience and learn new skills is to volunteer.
- InternshipPrograms.com - Large internship database featuring opportunities in a wide variety of sectors across the US and other large cities across the Globe.
- Internships.com - Extensive listings of internships from 7,000 companies, with additional tools to help you clarify your internship goals and fine-tune your internship search.
- Internships-USA (CEI Internships) - Access over 2,000 organizations offering internships and summer jobs in 12 different fields (username=UCBerkeley, password=GoldenBears)
- Vault Online Internship Database - Sign-in via Callisto

Note mathematics is not listed as a field for which they have internships opportunities:

Internship Opportunities in Specific Fields

Architecture, Planning & Environmental Design
Arts & Entertainment
Business
Communications
Education
Engineering & Computer Science
Environment

Career Fairs - Career Center sponsored career fairs offer internship and summer opportunities
Summer On-Campus Recruiting - Campus interviews with selected employers for summer opportunities
Work-Study - For financial aid students receiving work-study awards
Campus Opportunities - Campus-affiliated internships and experiential opportunities

Videos: Advice from Employers About Internships

Qualities Employers Look For
The Value of Internships