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Michael Dorff

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The benefits for students who do undergraduate research are mainly thought of in terms of graduate school success and opportunities for future careers as professors. These benefits also help students who go into business, industry, or government. Faculty mentors are often unaware of careers and internships in business, industry, or government. In this paper, some of these opportunities will be presented so that professors can better direct students to them as they are mentoring students. Much of this information has been obtained while organizing the summer internship program at Brigham Young University's Department of Mathematics, the "Careers in Math" speaker series funded by NSF grant DUE-1019594, and our academic-year undergraduate research program, which involves about 75 mathematics majors a year in original research.

1. The benefits of undergraduate research

Reports have shown that there are significant benefits for students who participate in undergraduate research in a science, technology, engineering, and mathematics (STEM) field [Bowen et al. 2009; Hathaway 2002; Hunter et al. 2006; Ishiyama 2001; Russell 2006; Seymour et al. 2004; Sharp et al. 2000; Summers and Hrabowski 2006]. These benefits can be summarized to include gains in knowledge and skills, academic achievement and educational attainment, professional growth and advancement, and personal growth [Osborn and Karukstis 2009]. With respect to mathematics, the MAA CUPM Subcommittee on Research by Undergraduates produced a 2006 report entitled "Mathematics research by undergraduates: costs and benefits to faculty and the institution" [MAASUB 2006]. The report states:

> Students receive tremendous benefit from this activity. Students get to be involved in a significant mathematics project under close supervision

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> by a professor. They gain experience with independent learning, a skill that will prepare them for research in graduate school as well as prepare them to be productive members of a company. They get control over their education in ways that are impossible to duplicate in the classroom environment. Students come out of this experience significantly enriched in their understanding of modern mathematics. Presentation of the results in written and oral formats improves the communication skills of the student.

Research projects for undergraduates can help them prepare for graduate school in mathematics. One way this is accomplished is by preparing students to make the transition from structured coursework to open-ended research. Although coursework provides foundational background in mathematical content, it is a different skill than the one used doing research which requires longer periods of work on a single problem without many inherent clues on how to prove results.

When we discuss undergraduate research, we often limit our thinking to students who will be attending graduate school and who eventually will becoming professors. However, many of the benefits mentioned above can help students who go into business, industry, or government. Often, professors do not know about careers and internships in business, industry, or government. In this paper, we will discuss some of these opportunities so that professors can better direct students to these possibilities as they are mentoring students.

2. "Careers in Math" speaker series

Seven years ago, we discovered something puzzling in the mathematics department at Brigham Young University (BYU). We had students who were excellent in mathematics but did not want to be mathematics majors. We asked them why. Their response was that they did not want to be a teacher or a professor. We told them that there are nonteaching careers using mathematics such as being a cryptographer or an actuary. Yet, later we found that these students still did not end up being mathematics majors. So, we decided we needed a more effective way to get the message to students that there are nonteaching careers for mathematics majors. To do this, we created a "Careers in Math" speaker series which has run for the past five years. For the speaker series we bring in 5–7 speakers who have a strong background in mathematics and who can show how mathematics can be used in business, industry, and government. The idea is to show students that mathematics is used in many careers and that taking mathematics courses is beneficial. Speakers come from various fields such as engineering, programming, operations research, finance, medical fields, actuarial sciences, government agencies, law, and even moviemaking.

When I mention our speaker series to mathematics faculty at other institutions, one question that is often asked is "How do you find speakers?" When I started the series, I knew only about a couple of nonteaching careers in mathematics, and I knew only one mathematician who worked in a nonteaching career — one of my Master's students who worked at the National Security Agency. So, first, I obtained a copy of our department's alumni list. I picked a few alumni who seemed like good candidates, and blindly emailed them. I explained what the speaker series was, that we were doing this to create awareness of career opportunities for mathematics students, and invited them to be one of our speakers. I was amazed by the positive response from alumni whom I did not know but who were eager to talk about mathematics and their careers. From there, things just grew. I mention to colleagues I meet at conferences what I am doing, and occasionally they will tell me of a contact who would be a good candidate as a speaker. Now I have more recommendations for speakers than I have spots.

Another question that I am asked is "How do you fund this?" Funding has been an unstructured aspect based upon the successful model of starting small and promoting successes to help you grow. When I first proposed the idea, the department chair liked it and was able to find some departmental funds to help us start the speaker series. The first year our expenses were small since I used local speakers and alumni who were visiting campus. However, we did arrange one main speaker whom we knew would give an excellent presentation. I made sure that a lot of students would be attending (offers of extra credit in classes and free donuts work like magic). Also, I invited the dean. The presentation was fabulous and the dean was so impressed that he offered some additional funds to support the speaker series for the next year. During the second year, we received an internal grant from the university to support internships among majors and adapted our speaker series by bringing in speakers from organizations that had summer internships for students. Also, we learned that some larger organizations have internal recruiters who visit campuses to give a presentation and will pay their own expenses. The next year, one of our previous speakers was involved in an NSF TUES grant proposal to promote applications of mathematics in the real world. This led to our speaker series becoming part of a collaborative NSF TUES grant funding us for $30,000 for several years (NSF grant DUE-1019594).

The speaker series has been a tremendous success. We are doing many activities to encourage more students to take mathematics courses and become mathematics majors, including the WeUseMath.org web site, the BYU IMPACT (Interdisciplinary Mentoring Program in Analysis, Computation, and Theory) lab that funds students to work on problems provided by business and industrial partners, the promotion of paid summer internships for our mathematics majors, and a new applied and computational mathematics emphasis connected to industry for our mathematics majors. Since we have started emphasizing career options in mathematics, we have had an 89% increase in the number of mathematics majors at BYU and this has resulted in the mathematics department receiving several new faculty positions.

3. What the employers have said about hiring mathematics majors

I have asked speakers and employers why they want to hire mathematics students. What do you think their response is? This is an important question. Think about it for a moment before you look at the answer. Mathematics majors should also think about the answer to this question. In fact, when I talk to students about this topic, I often ask them to tell me their answer. Why is it important for students to think about this? Because employers will not hire students just because they are mathematics majors. Instead, students need to convince their potential employer to hire them. Having thought about the answers to the question "Why hire a mathematics major?" provides students with some excellent talking points in an interview with an employer. So, what are the reasons the speakers and employers have given? They have said that they want to hire mathematics majors, because of the students' problem solving skills, attention to detail, ability to abstract, methodical approach, and the different perspective they bring to problem-solving.

Paying attention to detail is a characteristic that I did not think of at first. A BYU mathematics major was looking for a job and had interviews with five companies. In two of those interviews, she was asked a question similar to the following: "Suppose you have a clock with an hour hand and a minute hand, and the time was 1:25. What is the angle between the hands?" At first, someone would have to know that there is 360° all the way around the clock and so each five-minute interval represents 30°. Then some people would say that since there are 4 five-minute intervals between the 1 and the 5 on the clock, the answer would be $4 \times 30°$ or 120°. But that is not correct. Why? Because as the minute hand moves, the hour hand also moves. So, at 1:25 the hour hand is not pointing at 1 but is somewhere between 1 and 2. This is the type of detail that many mathematics majors are good at noticing.

Likewise, offering a different perspective on how to solve a problem is not an attribute that many mathematics students mention. Industrial firms and businesses create groups to work on problems. These groups often consist of people with different backgrounds such as programmers, scientists, engineers, statisticians, and mathematicians. These are effective, because each person brings a different perspective to solving a problem. It makes sense. The way an engineer approaches a problem is different from the way a mathematician does. Using these different perspectives provides a better result. As an aside, a solution to a problem in industry can be very different than a solution to an academic problem. In industry, the group is usually given a problem with a timeline and is told to come up with the best possible solution within that time frame. They are not necessarily looking for an exact answer but the best possible approximation given the constraints. Once the time period is over, the group will move on to another problem. They do not have the academic luxury of exploring nooks and crannies of a problem unless that is part of the group's task.

Just having these skills mentioned above is not enough to get a job. Students have asked "What should we do to better prepare ourselves for these careers?" Speakers and employers have recommended that students should

- know how to program,
- develop good communication skills (i.e., speaking and writing),
- have some background in some other STEM field such as statistics, computer science, or biology, and
- have experience working intensively on a hard problem whose solution is unknown (i.e., do an undergraduate research project or a summer internship).

Knowing how to program is an essential skill for a mathematics student who is interested in a career in industry. If a student does not know how to program, it will be extremely difficult for them to get a mathematics-oriented job. Most of the people in industry whom I talked with say that it is not too important which programming language students know. Instead, they say that having the experience of knowing how to program is what is most significant. If students have that experience, then they can more easily learn the programming language that the company needs. Students do not need to take a lot of programming courses, but they must be able to demonstrate their abilities to program. One way this can be done is during the job interview. One of BYU's graduating mathematics majors had been asked in at least two job interviews to describe how she would write a program to do a specific task such as taking a large set of random numbers and listing them from least to greatest, or determining which three-digit integers in a random set are prime.

Good skills in speaking and writing are also important. Often careers in business and industry require employees to work in groups that try to analyze a situation and find a solution. Good communication skills are helpful for success. Also, there may be times when an employee will need to explain a project to an executive who has little or no background in mathematics or convince an executive that the employee's group has an important project to which the company should allocate resources. The employee may be initially asked to give a 30-minute presentation but then, due to unforeseen circumstances, may have to shorten the presentation to 10 or even 5 minutes. A great skill is to be able to present the technical ideas of a project in a way that a nontechnical person can understand, while being flexible enough to give the highlights in a short 2-minute elevator speech or expand it with significant details for a longer 30-minute presentation. For more thoughts on this, see the book *The Persuasive Wizard* [Givens 2011]. This fits well into an undergraduate research experience since students can learn these skills as they explain their research to others through seminar and conference presentations and through posters and research reports/papers. I especially think of the MAA's student poster session at the Joint Meetings as a useful training stage for such a skill.

Studying advanced undergraduate mathematics and solving a homework problem from the textbook is often difficult for students. But it takes a different kind of difficulty to work on an open-ended research problem in an undergraduate research setting or in an internship. Such situations require longer periods of work on a single problem without knowing if a solution is possible and if it is, not having many inherent clues on how to obtain that solution. Yet, this is very similar to the way problems are approached and tackled in industry. Skills obtained and experience learned in working intensively on a hard problem whose solution is unknown are great preparations for careers in industry.

4. Careers for mathematics majors

Which careers employ students who study mathematics and have the additional skills mentioned above? While there are numerous careers, let me share some examples from engineering, programming, operations research, data mining and analytics, finance, medical fields, government laboratories and agencies, and computer graphics. Additional careers can be found on web sites such as WeUseMath.org.

Engineering. When I first starting talking with employers, I was intrigued that engineering firms such as Raytheon, Boeing, and General Dynamics would employ mathematicians. I had naively thought that they would want to hire only engineers. But their recruiters pointed out that they form groups consisting of people with different backgrounds — engineers, programmers, statisticians, and mathematicians. This allows for different perspectives to be used in solving a problem. We have several alumni who work for Raytheon. These engineering firms often work on projects related to aerospace and defense. For example, Raytheon is working on a real "iron man suit"; check out some video clips on YouTube by searching for the terms *Raytheon* and *exoskeleton*. Recently, I talked with recruiters from Raytheon and from Boeing. They wanted to hire students who have a graduate degree in mathematics, but they were not getting many applicants.

Programming. As mentioned above, programming is an essential skill for any mathematics student who wants a mathematical career in industry or business. If a student has this skill, it is not difficult to find a job as a programmer. There are national companies such as: Epic, which creates software for medical groups and hospitals; FAST Enterprises, which provides software and technology consulting services for government agencies; and SirsiDynix, which develop technologies for university and community libraries. These are three examples of companies that are currently recruiting mathematics majors as programmers. There are many other companies from small start-ups to large international companies that are constantly in need of programmers.

Operations research. It applies analytical and mathematical methods to help make better decisions. It deals with such questions as "What is the optimal way to schedule a set of tasks?" and "What is the most efficient way to arrange the flow of traffic?" Examples of scheduling problems include the scheduling of a sport team's games, the restocking of large businesses such as Walmart, and the scheduling of surgery in hospitals (i.e., arranging physicians, patients, nurses, and operating rooms). Transportation problems include stop light synchronization, the evacuation plan for a building or a stadium in case of a terrorism threat, and efficient delivery routes for UPS or airlines. Eric Murphy does operations research for the government. I met him at an AMS regional conference. He has a PhD in complex analysis and works in the Pentagon advising the Joint Chiefs of Staff on how to best move supplies and troops in and out of foreign countries such as Afghanistan. Sommer Gentry does operations research as a research associate for the John Hopkins University School of Medicine and as a mathematics professor at the US Naval Academy. A few years ago she made national news when she teamed up with her husband, a surgeon, to use operations research to find a more efficient way to match kidney donations with recipients.

Data mining and analytics. Data mining deals with analyzing extremely large amounts of data. Think of all the data being created on the internet. In 2011, it was estimated that the Library of Congress had collected about 235 terabytes of data. Google estimates that the internet holds about 5,000,000 terabytes of data — 20,000 times as much as the Library of Congress. And it is growing. Data mining is a very hot area. Google uses data mining to improve its internet searching techniques, Netflix uses it to provide recommended new movies based upon a user's ratings of previously watched movies (read about the "Netflix Prize"), professional sports teams use it to improve their chances of winning (think of the movie *Moneyball*). For more examples, check out Richard De Veaux's presentation on data mining at the MAA's Distinguished Lecture Series at the Carriage House on April 20, 2012.

Finance. Last year I attended a STEM career fair. I talked to representatives from 15 companies who were specifically advertising to hire mathematics majors. Three of the companies were in finance — Goldman Sachs (global investment banking), RBS (global banking and markets), and Capital One (banking and financial analyst).

The RBS representative mentioned that one reason they hired mathematics majors was for their attention to detail. Also, all three of these banking firms have summer internships for students. In spring 2013, Kurt Overley will be speaking in our "Careers in Math" speaker series. Kurt has a PhD in applied mathematics and has worked in investment banking for the past twenty years as a pioneer in the hedge fund derivative industry.

Medical fields. As medical fields become attuned to data, mathematics can provide a solid foundation to begin the study of medicine. Helen Moore who has a PhD in geometric analysis is an example. Originally, Helen's interest did not lie in the medical field, but after attending some conferences and workshops related to mathematics and medicine, she became interested. Now, she works for Pharsight, a pharmaceutical company, as a senior scientist. When a pharmaceutical company develops a new drug, they must determine safe and effective dosages to prescribe to patients. Helen uses control theory and mathematical modeling to do this. Michael Cannon is a BYU alumnus with a BS in mathematics and a PhD in epidemiology. He works for the Center for Disease Control and Prevention (CDC) doing research on the prevention of birth defects.

Government laboratories and agencies. The National Security Agency (NSA) is the largest employer of mathematicians in the United States. They use mathematicians to work on cryptographic problems and complex algorithms, and I have had three alumni who work at NSA speak at BYU. There are also US government laboratories that hire students with a strong mathematics background. For example, Robert Berry was a Master's student of mine who now works at Sandia National Labs on energy problems, and Carol Meyers, who has a BA in mathematics and a PhD in operations research, works at Lawrence Livermore National Labs on problems related to nuclear disarmament and emergency disaster preparedness.

Computer graphics. I have to admit that when I first heard that mathematics was being used in movies, I thought it was a gimmick to devise some application of mathematics in today's society. Now, I see how wrong I was. Doug Roble at Digital Domain Productions, Inc. has mentioned that the top 17 money making movies from *Avatar* to *Toy Story* used mathematics in their creation. Tony DeRose, a research scientist at Pixar Animation Studios, gives talks on how mathematics has changed Hollywood. Ramus Tamstorf at Walt Disney Animation Studios, Adam Sidwell, an independent Creature Technical Director, and Doug Roble have all voiced this same message. They deal with issues of making the movement of animated characters, the light shading on characters, the flow of water, and the crashing of objects seem realistic. For example, early on, animated characters were triangulated with a grid. With the vertices of the grid points, a character could be moved using matrices. However, this approach requires a lot of computation — which translates into money and time. Tony DeRose's group devised a technique to enclose an animated character in a cage that requires about 75 times fewer grid points. They then developed mathematical algorithms so that when they moved the cage, the character also moved in a realistic way.

5. Internships for mathematics majors

Internships are a great way to help students who want to go into a career in business or industry. A good internship for a student is like doing undergraduate research with problems from business and industry instead of problems from academia. Mathematics majors from our department who have participated in summer internships at a given company have typically found salaried employment with those same firms after graduation. But just like undergraduate research, students need guidance in finding internship possibilities. Basically, we have found that there are two ways to find internships. First, look at opportunities with companies and organizations on the national level. These include internships with companies and firms at the national level that deal in finance, technology, science, aerospace and defense, and actuarial science. In addition, there are internships at government facilities such as the National Security Agency, national laboratories, and NASA. Here is a short list of some internship opportunities at the national level for mathematics students along with a current link to details about the internship.

- Government
  - National Security Agency: nsa.gov/careers/opportunities_4_u/students/index.shtml
  - Lawrence Livermore National Laboratory: internships.llnl.gov/
  - Los Alamos National Laboratory: lanl.gov/education/undergrad/internships.shtml
  - Argonne National Laboratory: dep.anl.gov/p_undergrad/spring.htm
  - National Aeronautics and Space Administration (NASA): usrp.usra.edu/
  - Naval Surface Warfare Center, Dahlgren Division NSWCDD: navsea.navy.mil/nswc/dahlgren/RECRUIT/studop.aspx
- Finance
  - Goldman Sachs: http://www.goldmansachs.com/careers/students-and-graduates/index.html
  - Bank of America: http://campus.bankofamerica.com/
  - Citigroup: internships.about.com/od/banks/p/citiinternships.htm
- Computers and Technology
  - IBM: www-03.ibm.com/employment/us/un_interns_coops.shtml

  - Microsoft: research.microsoft.com/en-us/jobs/intern/default.aspx
  - PARC, a Xerox Company: parc.com/about/careers/internship_program.html

- Science
  - SAIC: saic.com/career/students/interns.html
  - Metron: metsci.com/Default.aspx?tabid=254
  - Phillips: philips.com/about/careers/student/internships/index.page
  - Mitre: mitre.org/employment/student_opps.html

- Aerospace and Defense
  - Raytheon: jobs.raytheon.com/career-paths/campus-recruiting/internships-coops
  - Boeing: boeing.com/careers/collegecareers/
  - Aerospace Corporation: aerospace.org/careers/internships/

- Actuary
  - Prudential: http://goo.gl/iPXytD

Some web sites with more internship information are:

- siam.org/careers/internships.php
- ams.org/employment/internships.html

Second, there are regional and local internships. Also, developing connections with alumni who work at businesses or industries that offer internships are a valuable resource. We have found that these alumni can guide a student along the process and become professional mentors for them.

6. Conclusion

The world is becoming more mathematically oriented, and there are a lot of exciting careers for people who understand mathematics. Let your undergraduate students know about these careers. Remember that undergraduate research projects are not only beneficial for students who go into academia, they can also be a great preparation for mathematics students who plan to go into business, industry, or government.

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