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The Center for Industrial Mathematics and Statistics at Worcester Polytechnic Institute

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"*I like math a lot, but what can I do with it other than teach*?"

In order to enhance the educational, research, and professional experiences for students and faculty at Worcester Polytechnic Institute (WPI) and to help make contacts with business and industry, the Center for Industrial Mathematics and Statistics (CIMS) was established at WPI in 1997. Faculty and students work on research problems that come directly from companies and are of industrial and mathematical significance. CIMS research activities have included projects for mathematical sciences majors during the regular academic year, and the WPI REU Program in Industrial Mathematics and Statistics, which is supported by the National Science Foundation, the Department of Defense, and our industrial partners. Here we give an overview of our experience with the industrial research program, highlighting the processes, benefits, and challenges.

1. Mathematical scientists in business, industry, and government

According to data collected by the American Mathematical Society (available online at http://www.ams.org/profession/data/annual-survey/survey-reports), in the last five years around 25% of new recipients of doctorates in the mathematical sciences from US universities who took their first job in the US went to work in business, industry or government (BIG); see Table 1. When we remove those who wrote their dissertations in statistics or biostatistics — that is, we consider only mathematics dissertations — the portion is still significant and is between 15% and 20%; see Table 2. Between a third and a half of statisticians take up business, industry, or government jobs.

It behooves us therefore to ask:

- What is the role of a mathematician in business and industry?

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Year PhD completed	No. of new PhDs employed in US (first job)	No. of new PhDs employed in US (BIG)	Percentage of new PhDs employed in US (BIG)
2006–2007	1012	256	25.3%
2007–2008	1026	270	26.3%
2008–2009	1166	305	26.2%
2009–2010	1263	292	23.1%
2010–2011	1191	316	26.5%

Table 1. US employment information for new recipients of doctorates in the mathematical sciences.

Year PhD completed	No. of new PhDs employed in US (first job)	No. of new PhDs employed in US (BIG)	Percentage of new PhDs employed in US (BIG)
2006–2007	689	116	16.8%
2007–2008	730	135	18.5%
2008–2009	695	144	20.7%
2009–2010	867	139	16.0%
2010–2011	825	158	19.1%

Table 2. US employment information for new recipients of doctorates in the mathematical sciences, omitting those who wrote dissertations in statistics or biostatistics.

- What is it like to work with technical experts on a problem that requires significant mathematics but also must satisfy real-world constraints?
- What kind of mathematical and statistical tools are used to solve problems in business and industry?
- What skills are important to be successful?
- What can university faculty do to better prepare students?

The 1996 and 2012 SIAM reports on mathematics in industry [SIAM 1996; 2012] investigate some of these questions. In addition, the more recent report presents 18 case studies of business applications of mathematics which include business analytics, communications and transportation, computer systems, information technology, mathematical finance, manufacturing, oil discovery and extraction, systems biology, modeling of complex systems, and software development. The Center for Industrial Mathematics at Worcester Polytechnic Institute (WPI) also seeks to get closer to answering these questions by providing opportunities for students and faculty to conduct research with business and industry.

2. WPI and the Center for Industrial Mathematics and Statistics

Some people are driven to do mathematics mainly because of the appeal of the intrinsic beauty of the subject, while others have a greater need to see its connection and relevance to societal needs. Recognizing this, the Center for Industrial Mathematics and Statistics was established at WPI in 1997 to make closer ties between the university's mathematical sciences community and the world outside the academic walls. In the last 15 years, over 125 projects have been completed with over 70 different companies. The projects begin with real-life problems that are generated by our industrial partners and are of direct importance to them. Individual students or small teams, under the direction of one or more faculty members and one or more industrial liaisons, work on a problem of both industrial and mathematical significance.

Companies that work with CIMS do so because it helps the companies address their needs for mathematical solutions and enhance their technological competitiveness. Industry benefits by having access to

- the expertise of faculty members who can help identify and solve critical problems,
- bright, energetic students,
- the latest scientific research developments,
- state-of-the-art computing facilities,
- active participation in the educational process, and
- the opportunity to identify and help train potential future employees.

The existence of CIMS at WPI is feasible because of the nature of WPI and its educational philosophy and academic structure. WPI is a private university of engineering, science, technology, and business. The institute has had hands-on student research projects at its core in keeping with the university's motto of "Lehr und Kunst", which we translate as "theory and practice". In order to obtain a bachelor's degree, *every* undergraduate must complete a Humanities and Arts Project, an Interactive Qualifying Project which makes the connection between science and technology and society, and a Major Qualifying Project (MQP); see http://www.wpi.edu/admissions/undergraduate/academics/projects.html. Also, WPI faculty are expected to advise student research projects as part of their regular teaching duties.

The MQP is a senior-year project completed in their major field of study. It is often the work of a team and spans three-quarters to a full academic year. The purpose of the MQP is to provide a capstone experience in the student's chosen major that will develop creativity, instill self-confidence and enhance the student's ability to communicate ideas and synthesize fundamental concepts. In completing a mathematical sciences MQP, students will have put the theory that they learn in their courses into practice. They will have the opportunity to gain mathematical depth and to develop skills in problem-solving, communication, teamwork, and self-directed learning. With industrial projects, they also get the opportunity to interact with the outside world before starting their careers.

Mathematical sciences graduate students may also complete industrial projects as part of their MS and PhD requirements. In particular, students in the Professional Science Masters Program in Financial Mathematics, and the Professional Science Masters Program in Industrial Mathematics choose this option.

3. WPI REU Program in Industrial Mathematics and Statistics

The opportunity to work on real-world mathematics and statistics projects is not just afforded to WPI's undergraduates and graduate students. Through the WPI REU Program in Industrial Mathematics and Statistics, undergraduates from other universities can come to WPI and work with CIMS [Heinricher and Weekes 2007]. The REU program has been supported for 15 years from 1998–2012 by the National Science Foundation (DMS 9732338, DMS0097469, DMS 0353816, DMS 0649127, DMS1004795) and the ASSURE program of the Department of Defense. We have hosted 167 students from 121 colleges in 37 states. Our REU program will continue for the summers of 2013–2015 under award DMS1263127 from the NSF.

The REU Program in Industrial Mathematics and Statistics at WPI introduces students to the ways that advanced mathematics and statistics are used in industrial and financial settings. It provides an excellent experience for advanced undergraduate students going on to graduate school, whether they choose to specialize in applied mathematics or not. The implementation of mathematics to a particular industrial question is certainly valuable for students interested in following nonacademic career paths, but it is just as valuable for students who enter "traditional" graduate programs and go into academic careers. Students are challenged to understand a given problem and the needs of the sponsor, get to work, and communicate effectively the approach, results, conclusions, and recommendations. Over the course of the project, the research team meets several times with the project's industrial advisor. The students' final deliverables to the company include an oral presentation, a written report, and any accompanying computer programs.

In this REU program, students will experience some of the differences between industrial and academic cultures. For example, the problem that a company presents to the students will be given in the context of the company's operation and the potential impact of the solution to the company's business. The problem needs to be formulated mathematically in order to be understood and solved. These mathematical solutions can have a direct, and potentially large, monetary value for the company's bottom line; this is an experience not found in the traditional academic research environment. In addition, the mathematical solutions found need to be reported in the original corporate context and in a form from which strategic decisions may be made. The mathematics needed to answer the company's questions may be applications of known mathematical concepts or a new mathematical formulation that merits its own study.

K–12 impact. The industrial mathematics projects completed by WPI and REU students have become the foundation for successful outreach programs based at WPI. CIMS has organized five summer institutes for high school and middle school teachers on industrial mathematics called the *Mathematics in Industry Institute for Teachers* thanks to financial support from the GE Foundation, the NSF, SIAM, and ExxonMobil. The ultimate goal of the institute was to increase awareness on the part of teachers, students, and parents of the demand for mathematical scientists in government, business, and industry. More than 200 teachers from more than 100 schools in 18 states came to WPI to spend a week working on industrial mathematics projects. The attendees heard directly from mathematical scientists working in industry, and heard also from faculty and REU students about their work.

Teachers worked in small groups with faculty and undergraduates on industrial research projects. For example, there was a team of REU students working on a project in which they were studying the fluid flow through an electropneumatic pulsed jet actuator, which consists of a miniature valve connected to a convergent nozzle by a small flow chamber. Three middle school teachers and the faculty advisor reduced this project to one that was accessible and interesting to middle schoolers and in concert with the middle school curriculum. Middle school students would work on experimentation, data collection and graphing skills as they respond to a (fake) call from the Hasbro company to "find the best combination of the amount of water and number of pumps to operate the Supersoaker 4000". They would, of course, need to be supplied with a large volume of water, waterguns and, possibly, a change of clothing!

In parallel, NSF-funded Research Experience for Teachers (RET) participants developed a library of industrial projects for the high school classroom: the WPI Industrial Mathematics Project for High School Students. For three summers, 2–3 high school teachers supported by the RET supplement, worked in parallel with the REU students. In addition to attending the regular REU activities, they developed materials needed for classroom work. These projects are available on the web (see http://www.wpi.edu/academics/math/CIMS/IMPHSS/). One can find over 20 projects for high school students drawn from a variety of real-world situations that lead investigations in subjects ranging from algebra to calculus and statistics.

4. The "reality" of industrial project work

Problems from industry do not necessarily arrive neatly packaged and presented like those found at the end of the chapter in a textbook. They are real problems and reality is not pristine. Once the industrial sponsor has presented us with the problem that we have agreed would benefit from mathematical or statistical tools and analysis, the first thing that students must do is understand the industrial context of the problem. Why is this problem important to the company? What has the company attempted, if anything, by way of analyzing the problem? Once we have a good enough understanding of the science, engineering, or business end of things, we look at formulating the problem mathematically. We have found that *formulating the problem* and figuring out what mathematical questions need to be tackled may be as hard or sometimes harder than problem solving.

We find that the *project goals may evolve* as the project moves along. This is because, as we learn more about the problem, we may ask and encounter questions that were not thought about beforehand or could not have been foreseen without the investment of time and thought that the students researchers bring to the problem. We bring fresh pairs of eyes to each project that we take on and having bright students with new ideas and new perspectives is valuable to the industrial advisors whose views may be occluded by their prior history with the project.

Mathematical scientists in industry are often part of a team of people working together to solve problems. The team members often have a variety of backgrounds. It is important that our students be able to work on their own, but equally important that they develop the *teamwork* skills so necessary for successful collaborations with a diverse range of colleagues.

It cannot be overstated how critical *communication skills* are. One has to learn the language of the core discipline in which the research problem lies so that confusion does not arise. It is important that students learn early to ask questions about the industrial problem and to keep asking questions until they understand. The problems that are being encountered are completely new to them and often completely new to the faculty advisor. We have found that when one is not quite convinced of something, it is often not correct, or, as sometimes happens, that we have been speaking different languages and need to take the time to define terms clearly. Questions also help refine the goal and direction of the research.

The most wonderful research is not of much use if it is not communicated effectively. It is not enough to convey how much work has been done; it must be conveyed what has been done and this explanation has to be at a level suited to the audience. Students in our REU program make weekly oral presentations showing their progress and, ultimately, the students are required to write up their research work in a formal document that is given to the sponsor.

Industrial mathematics projects have impact because mathematics and statistics are used to make real decisions. We may often have to aim not for the best solution, but for a very good solution since, in the real world, one works within time and resource constraints. There is rarely one right answer — we are dealing with models often, after all — but there are good solutions and bad solutions, and it is important to be able to examine, understand, and articulate their strengths and limitations.

Getting industrial research projects. To find industrial research projects that are suitable for students, one may start with the career center at one's university to see which employers are looking for mathematical sciences students — that is, students with quantitative and analytical skills. It also makes sense to see where graduates of one's department have gone on to work and to contact those alumni directly. Initial contacts with a company may be made via friends, alumni, trustees, and even strangers. It is then necessary to find out who would be the right person to communicate with at the company to advocate for the connection with you and your department, and then to put forward project ideas. Persistence and initiative are a must.

There are certainly many challenges when pursuing a company for projects. For instance, the company may be actually interested in building a research relationship but may be too busy to put the time and effort into such a new venture. The potential sponsor must feel that the time, hence, the money (since time = money) it commits to the collaboration will be worth the return. Earlier in this article the benefits of student research to industry were set forth, but new companies in particular may need to be convinced of these.

The appropriate faculty member with the right mathematical expertise and interest must be found who can discuss the project idea and scope with the project sponsor. The potential mathematical content of the project must be assessed to make sure that the level is neither too high nor too low for the student in question.

One must assemble the right team of students. Aside from looking at coursework and technical skills, one would want students who come with enthusiasm and an interest in doing mathematics that is truly applied and with a nontrivial multidisciplinary flavor. Ideally, the students would provide a mix of strengths; for example, some may be better programmers than others.

Finally, industry has a guarded culture of intellectual property compared to the relatively open culture of academic research. The degree of openness varies from company to company and from project to project. Both the needs for corporate discretion on specific technical details of a problem and the academic transmission of new general mathematical results need to be fulfilled. When we work with industrial sponsors, legal agreements must be signed so that the university and the company are clear with regards to the use of data, confidentiality and proprietary information, intellectual property, and payment. Such an agreement may require several rounds of revision between our lawyers and those of the sponsor.

5. Conclusion

Mathematics and statistics problems abound in business, industry, and government, and we have found that students and faculty can make real contributions and help solve important problems. More information about the Center for Industrial Mathematics and Statistics, abstracts of past projects, and current activities can be found at http://wpi.edu/+CIMS.

We conclude with feedback from two companies about two REU research projects.

From an industrial sponsor's letter: *I very much enjoy working with the students since they bring a level of passion to the projects that is not often seen in industry. They bring a "can do" attitude to every study and that is always refreshing.... The torque model that WPI has helped us develop over the last 3–4 years has helped us make progress in fastener joint design for the projects we design. The torque model has direct applicability in supporting and improving our designs for assembly....*

I believe that these types of efforts help the student and our engineers. The students get an idea of what happens in industry. They can see how their discipline can be applied to various manufacturing problems. It also allows them to see and understand the compromises that sometimes need to be made given the constraints of the problem.... I have enjoyed working with the WPI family over several years and I plan to keep WPI in mind for future student projects.

From an industrial sponsor's letter: *Because the REU program provides faculty support and enables students to access the university IT infrastructure we are able to specify much more complex projects to challenge the students.... We were extremely impressed with the skill that the students displayed in the areas of financial mathematics and computing. Not only did the students meet the high expectations required by the complexity of the project, they showed genuine insight and at times even stumped the experts....*

Overall, the REU program opens the door to a realistic and complex learning experience that is not easily attainable in either a pure classroom or pure internship setting.

References

[Heinricher and Weekes 2007] A. C. Heinricher and S. L. Weekes, "Industrial mathematics and statistics research for undergraduates at WPI", pp. 193–197 in *Proceedings of the Conference on Promoting Undergraduate Research in Mathematics*, edited by J. Gallian, Amer. Math. Soc., 2007.

[SIAM 1996] Society for Industrial and Applied Mathematics, “The SIAM report on mathematics in industry”, 1996, http://siam.org/reports/mii/1996/report.php.

[SIAM 2012] Society for Industrial and Applied Mathematics, “The SIAM report on mathematics in industry”, 2012, http://www.siam.org/reports/mii/2012/report.php.

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