Mathematics Speaks to Industry (and Listens): The Stony Brook Program in Industrial Mathematics

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Cooperate, cooperate, cooperate. That is the founding principle of the Stony Brook program in industrial mathematics. From a vision and a concept in 1991, this program has grown into a robust activity. In the Department of Applied Mathematics and Statistics, we now conduct nearly a score of projects involving industrial partners. Since there is an interest in establishing similar programs elsewhere, we explain here some of the critical steps in getting started. Important features of our program will be applicable to other universities.

Our current and recently completed projects include:

1. Flow in heterogeneous porous media
2. Tracer tests for flow in porous media
3. Reliability estimates for flow in porous media
4. Geostatistics and characterization of heterogeneous porous media
5. Crystal growth
6. Manufacture of amorphous silicon panels
7. Fabrication of electronic devices
8. Manufacture of fiber reinforced composite materials
9. Thermal spray, for the manufacture of high quality surface coatings
10. Statistical quality control for the manufacture of ceramics

11. Control of electric power networks
12. Virtual reality for CAD/CAM manufacturing systems
13. Optimal path planning
14. Fast graphics systems
15. Health effects of ozone
16. Pattern recognition
17. Acoustic detection of engine wear
18. Text recognition and document processing
19. Speech recognition
20. Efficient computation of radar cross sections

More traditional academic labels for our research would be: scientific computing and numerical analysis, nonlinear and stochastic analysis, nonlinear PDE's and conservation laws, computational geometry, applied statistics and biostatistics. The individual projects grow organically out of our core research activities. Equally, they feed back into and enliven the core research we conduct.

In addition to our interactions with industry, we cooperate with numerous scientists and engineers in federal laboratories, at other universities and in other departments at Stony Brook on these and related projects. In the process, we also interact with university, regional, and state government administrative units.

The vision for this program originated with two reports, "The Mathematical Sciences, Technology, and Economic Competitiveness" [3] and "Mathematical and Computational Sciences in Emerging Manufacturing and Management Practices" [2]. These reports document the importance of quantitative modeling and mathematical problem solving for competitiveness in core industrial technologies; these reports also demonstrate foresight in their identification of industrial technologies as a national policy issue and of cooperation among industry, government, and academia as a means to address this issue.

Inspired by the publicity surrounding these reports, three junior pure mathematicians approached the author, with a request to start an industrial mathematics seminar. With this modest base of resources, the Stony Brook program in industrial mathematics was born. The seminar was easy to organize. We alternated between internal speakers (the three organizers) and external, industrial speakers. The internal lectures were based on chapters from A. Friedman's series, "Mathematics in Industrial Problems" [1]. Networking brought the external speakers: they were recruited on advice from colleagues and collaborators. We never found it necessary to make "cold calls." To this day, networking is by far the most important source of contacts for our various projects and activities. We have gained enough recognition to receive a certain number of cold calls, for which we are grateful, and one of our activities is supported by direct mail. In general, as we add new activities, the linkages become mutually reinforcing, as each tends to facilitate the others.

From the seminar series, we received our first industrial project, a request to evaluate a computational methodology under development at the home location of one of the speakers. The seminar facilitated focusing substantial resources on the project: the three organizers, two faculty from applied mathematics and two graduate students. With the talent and enthusiasm of this very sizable project team, and with the guidance of our industrial partner, we were able to learn areas of physics and numerical methods new to us. We corrected some errors, found relevant literature, parallelized the algorithm, rewrote the code, performed a series of large scale computations on parallel computers, and wrote two joint papers on extensions of the technology. We determined the class of problems to which the proposed technology could be applied and the quality of answers it would yield within its range of validity. The original assignment to evaluate the proposed technology was successfully completed.

About this time, a number of unrelated events allowed an expansion of our activities. It is probably the case that these opportunities resulted from the importance and timeliness of our agenda and also from the energy, enthusiasm, and visibility with which we were pursuing it.

The College of Engineering and Applied Science, in which Applied Mathematics and Statistics is located at Stony Brook, was preparing a planning document on Advanced Manufacturing. Using the documents cited above, Applied Mathematics was able to play a strong role in this study. A crisp, focused report was produced which won approval of engineering colleagues, university administrators and local high tech industrial firms. A Center for Advanced Manufacturing was formed. The Industrial Mathematics program is located within this Center. We obtained, as a consequence, access to and opportunities for collaboration with many programs throughout the College of Engineering. Today, for about a quarter of our projects, applied mathematics is a junior partner, with our engineering colleagues in the Center for Advanced Manufacturing being the senior partners. This arrangement is very important, as it allows us to participate at a small scale in cases where we lack the interest, resources, or knowledge to mount a self-sustaining independent project with industry. Among our collaborations of this nature are: thermal spray, crystal growth, fabrication of electronic components, and the control of electrical power distribution networks. While beginning our participation on scales we can handle successfully, we are also learning and internalizing relevant technologies. In this manner, we broaden the education of our students and the skill base we can offer future industrial partners.

A further planning document, Engineering 2000, charted an industrially focussed mission for the College of Engineering, and called for increased resources to accomplish this mission. Again, the above cited documents help[ed to strengthen the role that Applied Mathematics was able to play in this study. Again the study won wide support. In parallel, our dean's agenda to build industrial projects and collaborations provided a basis for a similar policy focus, which was approved by the university, the local business and political leaders, and the SUNY system. Cooperation with other Engineering programs in the SUNY system was important in moving from the planning stage to realization. Resources from this program will allow an expansion of our interactions with New York State industries. A small, but politically important award from the Long Island regional development authority accompanied this activity.

Starting in 1991, retirements and resignations opened three faculty positions. We succeeded in recruiting candidates who possessed industrial contacts as well as the strong qualifications we normally expect in the fundamental applied mathematical sciences. This recruitment allowed an instant doubling of the industrial mathematics program, and broadened the scope of the program to include industrial statistics and computational geometry. Resulting new industrial partners include aerospace firms, telephone companies and two Long Island firms whose technology problems specifically matched the skills of these new faculty members.

Our prior work on flow in porous media led to new industrial projects. One project, with two major oil companies, involves the study of flow patterns through heterogeneous geologies. Here we have established a partnership with a group at Los Alamos National Laboratory. Flow in porous media is also used to model the manufacture of fiber reinforced plastic composites by the Resin Transfer Molding (RTM) process. Previous contacts at Northrup-Grumman led to a project to study the origin and migration of microbubbles within the mold filling process. The RTM process is used in automotive and aerospace applications. In the latter case, the ability to form light weight, high strength structural components of complex geometries is especially important. Because microvoids can degrade the strength of the component by up to 50%, their control is very important.

Projects have come from diverse sources. A former graduate of our college started a company to apply pattern recognition to document processing. Realizing the resources and convenience of his alma mater, he came to us for assistance with technology. Our dean regularly schedules meetings with directors of technology for local industries. Several problems have resulted from these meetings. The Electric Power Research Institute (EPRI) requested a statistical study of the health effects of ozone. Our faculty develop industrial contacts at scientific meetings, leading to several current projects and others still under discussion. In June of 1994, we held a one day workshop on industrial mathematics. Each paper presented a collaborative industrial-academic project. Over 50 people attended. We expect to repeat this conference, perhaps annually. We expect it to lead to new projects, not only for ourselves, but for the participants from other institutions.

Most DoD and DOE Applied Mathematics funding programs welcome industrial and dual use applications in areas consistent with their mission and priorities. The NSF supports specifc industrial programs in mathematics. On this basis, we found no obstacles in the federal programs for the industrial projects we wanted to pursue.

Three educational initiatives have accompanied this research program. The most significant of these is an unusual course offered at Stony Brook by Dr. S. Weinig, Vice Chair and Director of North American Manufacturing, SONY, USA. The course was first offered in the Spring of 1993, and will be given again in the Fall of 1994. Manufacturing operations management is the central theme. Such a course is unusual for an applied mathematics department, but fits comfortably within an Operations Research curriculum. The chance to learn from a leading executive of SONY, who is also a sparkling lecturer, is the truly unique feature of this course. It will be offered throughout New York State via the SUNY engineering network, EnginNet, and it will be videotaped for wider distribution. Anyone wishing to learn how to reengineer or reinvent an organization, and anyone wishing to understand the management perspective of manufacturing, will benefit from following these lectures.

Our second educational initiative is short courses. We have offered a parallel computing tutorial several times. Over 35 people attended the most recent offering. One hour's work in the business library produced a data base of over 900 high tech firms in the region. These names were entered into a data base, and used to announce our tutorials. We plan to offer a tutorial in industrial statistics shortly. As our third initiative, we are beginning to offer, on an experimental basis, a Master's thesis based on problems arising in industrial practice.

In order to build awareness of and support for these projects at the departmental level, we have included short (five minute) project summaries as a component of faculty meetings. These short presentations also serve as preparation for presentations to our department's industrial advisory board and to our university administration.

Cooperation might be the single most important lesson we have learned in starting our program at Stony Brook. If so, the importance of listening would be the second.

Modeling and computation are more primary tools for industrial applications than theorems, but usually we find important theoretical issues to be understood within each application. Often, the theoretical questions are different in nature from those that emerge internally from theoretically driven research. They can be very interesting and in some ways more original. Deeper theoretical questions, which might not fit the time frames of an industrial project, may become the basis of a strong proposal with a federal agency. The intellectually challenging aspect of problems originating in industrial applications is beyond the scope of this article, which is focused mainly on how the start up phase of such a program can be managed. The deep connection between mathematical issues and problems of industrial importance was addressed in the reports [2,3].

Other groups, with the same overall goal, should invent their own recipes for starting an industrial mathematics program, based on their own strengths, the nature of their regional industries, and their potential or ongoing contacts with colleagues in laboratories and engineering departments. I suspect that many of their ingredients will be the same as ours.

The industrial mathematics seminar provides an excellent starting point for an industrial mathematics program. It is easily within the capabilities of most applied mathematics departments and groups. The flurry of report writing referred to above represents unique circumstances which most readers will not duplicate. However, the political force and the message of these reports rests on bedrock, and many of their consequences can be widely duplicated. Additional state and/or university resources for an industrial mathematics program which demonstrates initial success and a credible plan for growth have already been duplicated in several locations. Cooperation with engineering and applied science units is possible for most applied mathematics groups, but will require energy, persistence, tact, and a valuable technology to offer. Most of the methods used to generate projects at Stony Brook can be duplicated elsewhere. Probably totally different methods will also be devised. As we envisage this program at Stony Brook, the intellectual interest in solving interesting and important problems is its driving force, and necessary financial issues for its support are a secondary, but still important matter.

Perhaps the single most important conclusion we have demonstrated is that a program in industrial mathematics is both possible and intellectually rewarding. The proof is by existence. It is constructive and robust, and it appears to be invariant under time and space translations.

1. FRIEDMAN, A. *Mathematics in Industrial Problems*. IMA Volumes in Mathematics and its Applications Vol's 16, 24, 31, 38, 49 and 57, Springer-Verlag, New York–Heidelberg–Berlin, 1988 -.

2. FRIEDMAN, A., GLIMM, J. AND LAVERY, J. *The Mathematical and Computational Sciences in Emerging Manufacturing Technologies and Management Practices*. SIAM, Philadelphia, 1992.

3. GLIMM, J., Ed. *The Mathematical Sciences, Technology and Economic Competitiveness*. National Academy of Sciences Press, 1991.