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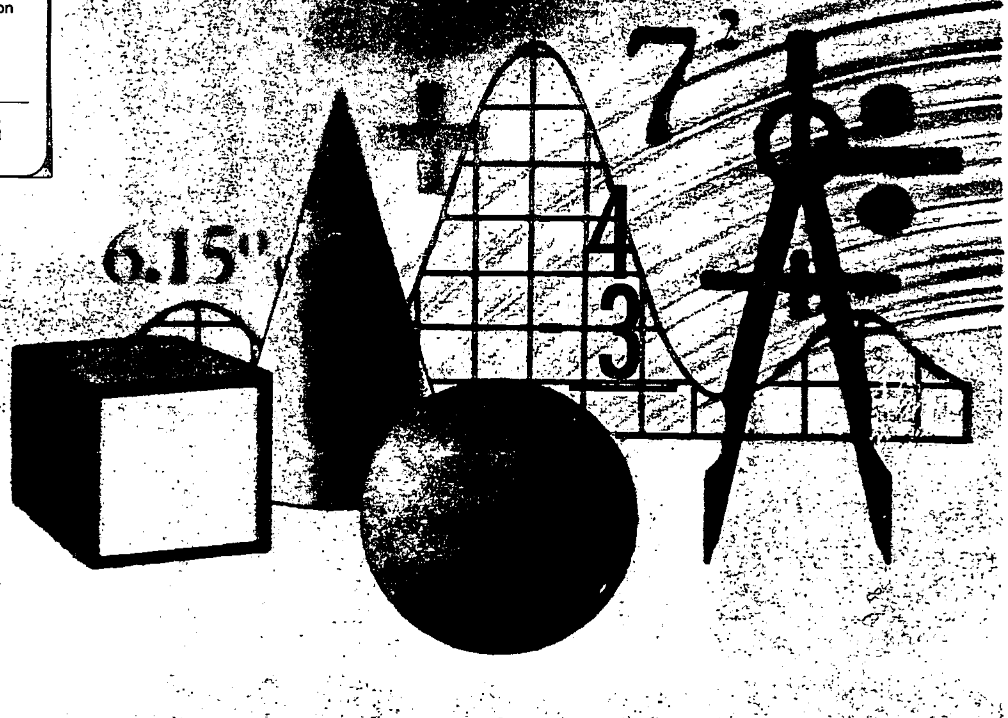
ABSTRACT

In 1995, the National Science Foundation (NSF) developed a special initiative called Mathematical Science and Their Application Throughout the Curriculum (MATC) which was designed to promote comprehensive improvements in undergraduate education that lead to increased student understanding of and ability to use the mathematical sciences. The program funded seven comprehensive projects which varied in focus and structure. This report provides detailed information about this initiative and its findings. It concludes that the mathematics initiative provides an opportunity for higher education institutions to work together to reform undergraduate mathematics education so that students are both more appreciative of the role of mathematics and mathematical thinking in academic and applied endeavors, and more able to use mathematics. The initiative is introduced and its development, interorganizational, and interdisciplinary arrangements are discussed. (ASK)

Mathematical Sciences and Their Applications Throughout the Curriculum: Final Report



Division of Undergraduate Education
Division of Research, Evaluation, and Communication
Directorate for Education and Human Resources
National Science Foundation

June 2000

Mathematical Sciences and Their Applications Throughout the Curriculum: Final Report

RED Contract 90-010

Naida C. Tushnet, Mary Ann Millsap, Jeanne Elliott, Beth Gamse, Marc Moss, Sheila Rosenblum

Division of Undergraduate Education
Division of Research, Evaluation, and Communication
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EXECUTIVE SUMMARY

In 1995, the National Science Foundation (NSF) developed a special initiative, Mathematical Sciences and Their Application Throughout the Curriculum (MATC), which was designed "to promote comprehensive improvements in undergraduate education that lead to increased student understanding of and ability to use the mathematical sciences" (*NSF Guide to Programs*, 1997). The initiative is an activity of the Course, Curriculum, and Laboratory Improvement Program of the Directorate for Education and Human Research's Division of Undergraduate Education, and is managed cooperatively with the Division of Mathematical Sciences. According to the *NSF Guide to Programs*:

> *Mathematical Sciences and Their Applications Throughout the Curriculum*–Promotes broad and significant improvement in undergraduate education that can lead to increased student appreciation of and ability to use mathematics. Comprehensive projects are expected to serve as national models for improving student understanding in the mathematical sciences, encouraging better integration of mathematics into other disciplines, and improving instruction in the mathematical sciences by incorporating other disciplinary perspectives. Projects must be multi- or interdisciplinary in approach, and involve several undergraduate disciplines.

The program funded seven comprehensive projects, which vary in focus and structure, the extent to which they involve other institutions of higher education, the characteristics of those institutions, the types of materials they develop, and their approach to "institutional change."

The projects are:

1. **Mathematics Across the Curriculum: Dartmouth College** began operation in 1995. At $4 million, the grant is one of the largest that the institution has ever received. The project involves multiple departments and is designed to result in a large body of instructional materials.

Dartmouth proposed to integrate mathematics into what they termed a "suitable proportion" of courses, including physics, chemistry, geology, biology, social science, economics, art, music, philosophy, computer, science, architecture, medicine, engineering, and literature. In the end, the materials were to be disseminated in modular form, including documented software, online modules, and videotapes.

Unlike the other projects, Dartmouth has no institutional partners, but individual faculty from Dartmouth co-teach with faculty at Union College and Vermont Technical College and have other informal relationships with faculty at a variety of institutions of higher education. Such arrangements provide an opportunity to test, evaluate, and revise modules. Further, Dartmouth has sponsored workshops to disseminate the products that involve faculty from a variety of institutions.

2. **Mathematics and its Applications in Engineering and Science: Building the Links** (Project Links; Rensselaer Polytechnic Institute with University of Delaware, University of Maryland, Virginia Polytechnic Institute, Siena College, and Hudson Valley Community College): Project Links began in the Fall of 1995 with a $4 million budget. It has developed instructional modules that include mathematics and at least one other discipline and employ available technology and multimedia formatting to present information, engage learners, and bridge disciplinary boundaries between mathematics and science or engineering applications. The project's goal is to create a library of materials to move instruction from a lecture-dominated mode to what RPI terms a "studio" or "workshop" mode. The process of developing modules will also serve to increase interdisciplinary interaction, thereby changing the institutional climate.

An Executive Committee comprising RPI faculty members from several departments and disciplinary perspectives oversees the work of the project, and five working groups each with a focus on a major area of mathematics with applications in science and engineering.

Project Links has developed modules that can be used in introductory mathematics, physics, and engineering courses, and, to some extent, in more advanced courses. To date, over 30 modules in five areas have been developed, using a common template, and most have been tested in studio class settings. The project has used its evaluation to inform project activities.

3. **Midatlantic Consortium for Mathematics and Its Applications Throughout the Curriculum** (MACMATC: University of Pennsylvania, Villanova University, Community College of Philadelphia, and Polytechnic University): The Midatlantic Consortium for Mathematics and its Applications Throughout the Curriculum (MACMATC) began operating in September 1996, with a $2.1 million budget. The project is a consortium of higher education institutions with different missions, including a Research-1 university (University of Pennsylvania), a university with a liberal arts focus (Villanova University), urban community college (Community College of Philadelphia), and the Society of Industrial and Applied Mathematics (SIAM). The project originally included a technical university, but it was never an active participant and is no longer part of the consortium.

The goal of the project is to integrate research and real-world applications into the basic mathematics curriculum as well as integrate advanced mathematics and computing into upper-level curricula of disciplines that use mathematics. Ultimately, the aim is to create a "climate in which faculty across all disciplines view themselves as being jointly responsible for the (technical) education of undergraduates, rather than as clients or servants."

The cross-campus relationships are highly valued, and cross-institutional activity occurs in the form of faculty exchanges and adoption of new courses. Regular meetings of leaders from each institution facilitate formal and informal communication and strengthen the interorganizational arrangement.

4. **Project Intermath** (The Consortium for Mathematics and its Applications [COMAP], US Military Academy, and additional institutions): Project Intermath began implementation in September 1996 with a grant of $2 million, with the Consortium for Mathematics and its Applications (COMAP) as the management agent. It builds on a successful reform initiated at West Point that had the objective of integrating curricula by developing student mathematics projects that are interdisciplinary in nature and require students to use mathematics concepts in appropriate contexts. The mathematics projects, known as "Interdisciplinary Lively Application Projects (ILAPs)," are tools to develop quantitative problem-solving skills; instill and reinforce the principles of mathematical modeling, scientific method, engineering through process and quantitative reasoning; and link faculty and students from different disciplines.

The project has eight "kernel" schools (West Point, Carroll College, Harvey Mudd College, Macalester College, Oklahoma State University, Texas Southern University, Tulane University, and Redlands University) and additional institutions (including historically black institutions and those serving other underserved populations, such as Hutson-Tillotson, Texas Southern University, Wiley College, Georgia College and State University , Clark Atlanta University and three Tribal Colleges), Dullknife Memorial Community College, Stone Child Community College, and Little Big Horn College). Most participating institutions have a local coordinator, and the Tribal Colleges work under the supervision of Clark Atlanta University. Annual meetings of coordinators review activities and plan for the following year.

The project's strategic approach is to change the culture of teaching undergraduate mathematics by integrating the curriculum within mathematics and across disciplines, having faculty across disciplines work together on curriculum design to foster interdisciplinary activity and curricular reform, and serve as a catalyst for institutional reform.

5. **Multimedia Mathematics: Across the Curriculum and Across the Nation** (University of Nebraska, Lincoln, and Oklahoma State University with Chadron State University, University of Tulsa, Tulsa Junior College, and

Metropolitan Community College) began operations in the fall of 1996, with a reduced budget of $946,000. As a result, the University of Nebraska, Lincoln , focused on interdisciplinary efforts involving physics and biology, and Oklahoma State University on chemistry and engineering. Each is developing courses that apply mathematics principles and concepts in the other disciplines through the integration of interactive technology in laboratory-like classroom settings. The new materials are envisioned as part of existing courses, and students will have repeated exposure to mathematical applications through CD-ROMs and print materials.

Four co-principal investigators manage the project, three from mathematics and one from physics, with two at each campus. There is little involvement of other faculty or collaborative work across the campuses, in part a result of the limited budget.

6. **Long Island Consortium for Mathematical Sciences Throughout the Curriculum** (Long Island Consortium for Interconnected Learning, (LICIL). State University of New York, Stony Brook, C.W. Post College, Dowling College, Nassau Community College, SUNY Agricultural and Technology College at Farmingdale, SUNY College at Old Westbury, CUNY-New York, New York Institute of Technology, St. Joseph's College, and Suffolk Community College): LICIL was originally funded in the Fall of 1996 with $2.8 million. The Consortium is headquartered at SUNY, Stony Brook (a Research-1 University), and includes 9 additional colleges and universities on Long Island: C.W. Post College, Dowling College, Nassau Community College, SUNY Agricultural and Technology College at Farmingdale, SUNY College at Old Westbury, CUNY-New York, New York Institute of Technology, St. Joseph's College, and Suffolk Community College. LICIL is attempting to develop an environment for interconnected learning in mathematics courses in mathematically based disciplines. It builds on preexisting reform efforts and encourages faculty in mathematics and mathematics-based disciplines to collaborate with colleagues as well as implement new pedagogies.

Two levels of administration support project efforts. At the Consortium level, an Executive Committee acts as the institutional watchdog/organizer/supporter for Consortium-wide activities, such as forums and dissemination efforts. Each participating institution has committees to direct and support its activities.

LICIL uses two strategies to pursue its goals. First, it supports consortium-wide activities to generate professional development through collegial interactions. Second, it makes annual development awards to faculty for activities that advance LICIL goals, such as grants to faculty who work across departments on innovative approaches to teaching mathematics. To receive funding in subsequent years, faculty must show that they have involved additional people across department or institutional boundaries.

7. **Mathematics Throughout the Curriculum** (Indiana University, Bloomington; Indiana University-Purdue University, Indianapolis, and the other six campuses of Indiana University): The mathematics initiative project housed at Indiana University at Bloomington began in Fall, 1996, with a budget of $2.8 million. The proposed restructuring of mathematics within the university system was to be accomplished by creating interdisciplinary courses and developing academic and social infrastructures. The courses and infrastructures were designed to encourage students to see the relationship of mathematics to other subjects, work, and their own goals, as well as to make positive changes in mathematics teaching and learning on the eight Indiana University campuses and beyond.

The project began with a Steering Committee, since reformulated into an Executive Committee that represents three campuses and a cross section of disciplines. The Executive Committee oversees and approves all new course design, documentation, and implementation. A faculty campus coordinator manages the project on each campus.

The project strategy is to fund interdisciplinary teams to develop courses for broader dissemination. Further, the campus steering committee representatives help to make connections for the interdisciplinary teams, each of which receives support to create and pilot test new courses in mathematics and other disciplines, particularly courses that emphasize project-based learning and technology.

NSF contracted with WestEd and Abt Associates Inc. to provide external monitoring for the seven mathematics initiative projects. Three key questions framed the monitoring activities:

- To what extent do projects implement activities and structures to achieve the goals of the initiative?
- To what extent can the activities and structures be sustained?
- To what extent do the projects transport their work to other institutions?

For two years, monitoring involved reviewing project documents, including the proposal, project annual reports, reports of National Visiting Committees, and other materials supplied by the projects, as well as two- or three-day site visits. One staff member from WestEd or Abt Associates Inc. accompanied by two content experts conducted the site visits, which resulted in a monitoring report. Following the site visits, contractor staff members and as many of the content experts as possible met at NSF for a day-long session that reviewed the findings and highlighted issues to share with NSF. This final report reflects the deliberations of the group's meeting in Spring 1999, as well as analyses of the site visit reports and supporting documentation.

Findings

The mathematics initiative is a direct descendant of the Course and Curriculum Development (CCD) calculus reform effort, which led to major changes in undergraduate mathematics education spurred by curriculum development and implementation. The successful strategy of bringing about extensive reform using curriculum as a key leverage point is central to the mathematics initiative, which is designed to expand the traditional boundaries of the mathematics instruction in higher educational settings. The seven grantee consortia are involved in some combination of the following activities:

- Designing and implementing courses;
- Designing and implementing instructional modules; and
- Implementing new pedagogies.

All mathematics initiative projects endeavored to develop new approaches to teaching mathematics, although there were differences in how they proceeded. Some started with broad ideas about new courses, and texts and/or manuals came later. Others followed a well-defined method for developing materials, focusing on specific disciplinary areas, sometimes with a systematic template and perhaps a publishing and dissemination strategy. In still other cases, projects provided guidelines for material and course development, leaving the process open. However, all projects shared the goal of developing materials that tied mathematics with other disciplines.

The seven projects entail interorganizational arrangements, partnerships, or consortia that connect multiple separate institutions with one another. Except for Dartmouth, which has informal arrangements with other institutions, the projects have formalized consortial relationships, although the effectiveness of the ties varies. This section focuses on the project structures that support the interorganizational arrangements, including how projects are organized and managed to achieve the goals of the initiative.

Most mathematics initiative consortia consist of a variety of types of institutions (e.g., major research universities, teaching colleges, technical colleges, community colleges). The composition of the consortia varies in geographical dispersion, ranging from all the institutions being in one region (e.g., LICIL), to one that is spread across the U.S. (e.g., Project Intermath).

The projects were largely able to reach across institutional barriers and develop strong interorganizational relationships. Further, such relationships existed between and among IHEs with similar purposes and characteristics and those with different missions. Relationships were strengthened through regular meetings, professional networks that existed prior to the project, the quality and reputation of the lead principal investigator and his/her institutional home, and open and mutually respectful communication. Although not all these factors were present in successful projects, the projects that showed progress toward achieving the program goals of increasing student appreciation of and ability to use mathematics had more than one of these characteristics. In addition, projects that paid attention to the relationships among participating institutions and understood that they could learn from one another were more likely to be successful than those that viewed interorganizational arrangements as a one-way street.

The seven projects vary widely in how they implemented interdisciplinary arrangements. However, projects used two different types of approaches, collaboration and consultation. These approaches existed simultaneously within each project and across participating institutions. Interdisciplinary arrangements are the core of the initiative. Both collaborative and consultative arrangements were implemented in the projects, and were effective in the majority of them. The factors associated with successful approaches to interdisciplinary arrangements included fit with the local context that generated administrative support, leadership and training, and methods of overcoming cost barriers. When such characteristics were present, faculty focused their energy on developing and implementing interdisciplinary courses. The seven projects approach dissemination in different ways. For some, the consortium itself represents the major mechanism for disseminating instructional approaches and materials. Dissemination occurs through the development of collaborative relationships across disciplines or departments and across institutions, as well as through consortium-wide workshops and conferences. For many of the projects, the partner institutions within the consortia serve as pilot sites for one another's courses and modules. For others, dissemination was more national.

Most projects view traditional publication as a major avenue for disseminating their materials. Although several projects are pursuing commercial publication, others are relying on the growing role of the Internet as an alternative means of making their materials widely available. Further, the projects use workshops, conferences, newsletters, and publishing articles in journals to spread information about their products, ideas, and processes to individuals and institutions beyond the institutions involved in the consortia.

The material outputs of the program are the most likely to be institutionalized, just as they are the easiest content for dissemination because IHE faculty define themselves in their instructional role, and course revision is part of that role. Consequently, across the projects, examples of the continuation of reform courses, or the inclusion of modules within courses, are most prevalent. In addition, some projects have stimulated the development of interdisciplinary and cross-institutional relationships that seem likely to endure. Even with the successes, however, challenges to institutionalization are great, and the discussion of those challenges will be used to lay the groundwork for the discussion of the factors that seem to support institutionalization.

Conclusion

The mathematics initiative provides an opportunity for these institutions of higher education to work together to reform undergraduate mathematics education so students are both more appreciative of the role of mathematics and mathematical thinking in academic and applied endeavors and more able to use mathematics. The program design builds on earlier success in calculus reform. The reform of the calculus included new curricula that embodied new pedagogical approaches, as well as formal and informal networks that facilitated dissemination of materials and pedagogy.

The mathematics initiative expands both elements, encouraging faculty to reform materials and pedagogy in a wide variety of courses, both within mathematics and in other disciplines. It also fostered formal interorganizational arrangements that nurture exchange of ideas, materials, and approaches. Overall, the program presented grantees with a view that improvement in undergraduate mathematics entails a number of nearly simultaneous changes–in curriculum and in relationships within and across disciplines, as well as relationships within and across institutions.

The seven projects funded as part of the mathematics initiative each approached the reform effort in a somewhat different manner, but most embraced the goal of improving student understanding of mathematics through integrating mathematics into other disciplines and incorporating other disciplinary perspectives into mathematics teaching. Overall, developing interdisciplinary links was most common with disciplines closest to mathematics, particularly engineering and the physical sciences. With a few exceptions, interorganizational arrangements were most easily accomplished across institutions that were also close, either geographically or in mission.

All seven projects are likely to sustain at least some aspects of the NSF-funded effort. Of all activities, new courses or modules are the most likely to be institutionalized. In addition, projects that developed intellectual communities and support for changed pedagogy and the use of technology seem likely to sustain such efforts. On the other hand, barriers to continuation exist, including university policies related to course listings and enrollment requirements, as well as the availability of necessary technology. When projects were able to overcome such barriers, they relied on strong leadership with knowledge of how best to influence policy, as well as existing policies, such as requirements for mathematical understanding, that supported the reforms that were undertaken.

NSF funded the seven projects to become "national models" for undergraduate reform. As such, project participants have paid attention to disseminating their efforts. However, the nature of the reform makes dissemination challenging. The greatest dissemination successes have been with curriculum and course materials, an area in which faculty have experience, but even in this arena new technologies challenge old practice. Project participants are also interested in disseminating pedagogical approaches, and the processes they used to develop materials and/or relationships, but these topics present greater challenges.

INTRODUCTION

In 1995, the National Science Foundation (NSF) developed a special initiative, Mathematical Sciences and Their Application Throughout the Curriculum (MATC), which was designed "to promote comprehensive improvements in undergraduate education that lead to increased student understanding of and ability to use the mathematical sciences" (*NSF Guide to Programs*, 1997). The initiative is an activity of the Course, Curriculum, and Laboratory Improvement Program of the Directorate for Education and Human Research's Division of Undergraduate Education, and is managed cooperatively with the Division of Mathematical Sciences. According to the *NSF Guide to Programs*:

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The projects are:

1. Mathematics Across the Curriculum: Dartmouth College
2. Mathematics and its Applications in Engineering and Science: Building the Links (Project Links; Rensselaer Polytechnic Institute with University of Delaware, University of Maryland, Virginia Polytechnic Institute, Siena College, and Hudson Valley Community College)
3. Midatlantic Consortium for Mathematics and Its Applications Throughout the Curriculum (MACMATC: University of Pennsylvania, Villanova University, Community College of Philadelphia, and Polytechnic University)
4. Project Intermath (The Consortium for Mathematics and its Applications [COMAP], U.S. Military Academy, and additional institutions)
5. Multimedia Mathematics: Across the Curriculum and Across the Nation (University of Nebraska, Lincoln and Oklahoma State University with Chadron State University, University of Tulsa, Tulsa Junior College, and Metropolitan Community College)
6. Long Island Consortium for Mathematical Sciences Throughout the Curriculum (Long Island Consortium for Interconnected Learning, (LICIL). State University of New York, Stony Brook, C.W. Post College, Dowling College, Nassau Community College, SUNY Agricultural and Technology College at Farmingdale, SUNY College at Old Westbury, CUNY-New York, New York Institute of Technology, St. Joseph's College, and Suffolk Community College)
7. Mathematics Throughout the Curriculum (Indiana University, Bloomington; Indiana University-Purdue University, Indianapolis, and the other six campuses of Indiana University)

NSF contracted with WestEd and Abt Associates Inc. to provide external monitoring for the seven mathematics initiative projects. Three key questions framed the monitoring activities:

- To what extent do projects implement activities and structures to achieve the goals of the initiative?
- To what extent can the activities and structures be sustained?
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For two years, monitoring involved reviewing project documents, including the proposal, project annual reports, reports of National Visiting Committees, and other materials supplied by the projects, as well as two- or three-day site visits. One staff member from WestEd or Abt Associates Inc. accompanied by two content experts conducted the site visits, which resulted in a monitoring report. Following the site visits, contractor staff members and as many of the content experts as possible met at NSF for a day-long session that reviewed the findings and highlighted issues to share with NSF. This final report reflects the deliberations of the group's meeting in Spring, 1999, as well as analyses of the site visit reports and supporting documentation.

According to site visitors, projects have developed courses and modules that meet the program guidelines, including some materials that content experts believe hold much promise. Stimulating institutional change has been more difficult, although signs exist that reform is well underway at a number of participating institutions, and the team identified factors associated with successful change. Projects are using a variety of mechanisms for disseminating their output, including the use of the World Wide Web, but most dissemination is focused on the curriculum products, not interorganizational or within-institution reform, which may limit the program's impact on undergraduate education.

The report is organized as follows: The first section presents an overview of each project, in order to provide readers with a framework for the remainder of the report. The report then focuses on four major sets of questions:

1. What course and curriculum materials did projects develop? What was the quality?
2. How did projects organize themselves to accomplish their goals? What were the interorganizational and interdisciplinary arrangements? What factors were associated with successful arrangements?
3. To what extent are mathematics initiative approaches being institutionalized? What factors are associated with successful institutionalization?
4. What did they disseminate? What means did they use? With what success?

Project Overviews

This section contains a brief description of each project, including the management structure and the overall strategy each is implementing to achieve program goals.

Mathematics Across the Curriculum: Dartmouth College

The Dartmouth College Mathematics Across the Curriculum project began operation in 1995. At $4 million, the grant is one of the largest that the institution has ever received. The project involves multiple departments and is designed to result in a large body of instructional materials.

Dartmouth proposed to integrate mathematics into what they termed a "suitable proportion" of courses, including physics, chemistry, geology, biology, social science, economics, art, music, philosophy, computer, science, architecture, medicine, engineering, and literature. In the end, the materials were to be disseminated in modular form, including documented software, online modules, and videotapes.

Unlike the other projects, Dartmouth has no institutional partners, but individual faculty from Dartmouth co-teach with faculty at Union College and Vermont Technical College and have other informal relationships with faculty at a variety of institutions of higher education. Such arrangements provide an opportunity to test, evaluate, and revise modules. Further, Dartmouth has sponsored workshops to disseminate the products that involve faculty from a variety of institutions.

The project is managed by a Steering Committee of seven co-principal investigators who meet every other week to review progress. In addition, five groups oversee topics that have resulted in new classes and materials. These topics are: data use, the first college year, mathematics in the humanities, modeling real phenomena, and discrete mathematics. Currently, the project is grappling with the logistical challenges of publishing the materials that have been developed.

In sum, the Dartmouth project focuses primarily on the development of materials in order to provide broad-based enrichment of mathematics education at Dartmouth and export the materials in a variety of courses to other institutions.

Mathematics and Its Applications in Engineering and Science: Building the Links (Project Links: Rensselaer Polytechnic Institute, with University of Delaware, University of Maryland, Virginia Polytechnic Institute, Siena College, and Hudson Valley Community College)

Project Links began in the Fall 1995 with a $ 4 million budget. It has developed instructional modules that include mathematics and at least one other discipline and employ available technology and multi-media formatting to present information, engage learners, and bridge disciplinary boundaries between mathematics and science or engineering applications. The project's goal is to create a library of materials to move instruction from a lecture-dominated mode to what RPI terms a "studio" or "workshop" mode. The process of developing modules will also serve to increase interdisciplinary interaction, thereby changing the institutional climate.

An Executive Committee comprising RPI faculty members from several departments and disciplinary perspectives oversees the work of the project, and five working groups, each with focus on a major area of mathematics with applications in science and engineering. The working groups include faculty members from mathematics and various engineering and science departments. The two co-principal investigators are chairs of the mathematical sciences and biomedical engineering departments.

Project Links has developed modules that can be used in introductory mathematics, physics, and engineering courses, and, to some extent, in more advanced courses. To date, over 30 modules in five areas (corresponding to the working groups) have been developed, using a common template, and most have been tested in studio class settings. The project has used its evaluation to inform project activities.

Midatlantic Consortium for Mathematics and Its Application Throughout the Curriculum (MACMATC) (University of Pennsylvania, Villanova University, Community College of Pennsylvania, and Polytechnic University)

The Midatlantic Consortium for Mathematics and its Applications Throughout the Curriculum (MACMATC) began operating in September 1996, with a $2.1 million budget. The project is a consortium of higher education institutions with different missions, including a Research-1 university (University of Pennsylvania), a university with a liberal arts focus (Villanova University), and an urban community college (Community College of Philadelphia), and the Society of Industrial and Applied Mathematics (SIAM). The project originally included a technical university, but it was never an active participant and is no longer part of the consortium.

The goal of the project is to integrate research and real-world applications into the basic mathematics curriculum as well as integrate advanced mathematics and computing into upper-level curricula of disciplines that use mathematics. Ultimately, the aim is to create a "climate in which faculty across all disciplines view themselves as being jointly responsible for the (technical) education of undergraduates, rather than as clients or servants."

The cross-campus relationships are highly valued, and cross-institutional activity occurs in the form of faculty exchanges and adoption of new courses. Regular meetings of leaders from each institution facilitate formal and informal communication and strengthen the interorganizational arrangement.

The underlying strategy of the project is to encourage innovative course development by providing funds to individuals and groups of faculty with interesting ideas for new courses and redesigns of other courses.

Project Intermath (The Consortium for Mathematics and its Applications, US Military Academy and 12 other institutions)

Project Intermath began implementation in September 1996 with a grant of $2 million, with the Consortium for Mathematics and its Applications (COMAP) as the management agent. It builds on a successful reform initiated at West Point that had the objective of integrating curricula by developing student mathematics projects that are interdisciplinary in nature and require students to use mathematics concepts in appropriate contexts. The mathematics projects, known as "Interdisciplinary Lively Application Projects (ILAPs)," are tools to develop quantitative problem-solving skills; instill and reinforce the principles of mathematical modeling, scientific method, and engineering through process and quantitative reasoning; and link faculty and students from different disciplines.

The mathematics initiative grant provides support to a variety of participating institutions in their efforts to develop and use ILAPs. Intermath project staff help institutions in the consortium by sponsoring workshops, conferences, and grant funds to meet project objectives. COMAP publishes the ILAPS.

The project has eight "kernel" schools (West Point, Carroll College, Harvey Mudd College, Macalester College, Oklahoma State University, Texas Southern University, Tulane University, and Redlands University), and additional institutions (including historically black institutions and those serving other underserved populations, such as Hutson-Tillotson, Texas Southern University, Wiley College, Georgia College and State University, Clark Atlanta University and three Tribal Colleges,- Dullknife Memorial Community College, Stone Child Community College, and Little Big Horn College). Most participating institutions have a local coordinator, and the Tribal Colleges work under the supervision of Clark Atlanta University. Annual meetings of coordinators review activities and plan for the following year.

The project's strategic approach is to change the culture of teaching undergraduate mathematics by integrating the curriculum within mathematics and across disciplines, having faculty across disciplines work together on curriculum design to foster interdisciplinary activity and curricular reform, and serve as a catalyst for institutional reform.

Mathematics Throughout the Curriculum (Indiana University, Bloomington; Indiana University-Purdue University, Indianapolis; and the other six campuses of Indiana University)

The mathematics initiative project housed at Indiana University at Bloomington began in Fall, 1996, with a budget of $2.8 million. The proposed restructuring of mathematics within the university system was to be accomplished by creating interdisciplinary courses and developing academic and social infrastructures. The courses and infrastructures were designed to encourage students to see the relationship of mathematics to other subjects, work, and their own goals, as well as to make positive changes in mathematics teaching and learning on the eight Indiana University campuses and beyond.

The project began with a Steering Committee, since reformulated into an Executive Committee that represents three campuses and a cross section of disciplines. The Executive Committee oversees and approves all new course design, documentation, and implementation. A faculty campus coordinator manages the project on each campus.

The project strategy is to fund interdisciplinary teams to develop courses for broader dissemination. Further, the campus steering committee representatives help to make connections for the interdisciplinary teams, each of which receives support to create and pilot test new courses in mathematics and other disciplines, particularly courses that emphasize project-based learning and technology. The project also leverages existing efforts, such as the IU Consortium for Undergraduate Education, based at Bloomington, which is involved in supporting broad institutional changes in teaching and learning.

The project has sponsored the development of courses in history, criminal justice, linguistics, business mathematics, nursing, finite mathematics, and biology.

Long Island Consortium for Mathematical Sciences Throughout the Curriculum (Long Island Consortium for Interconnected Learning, (LICIL): State University of New York, Stony Brook, C.W. Post College, Dowling College, Nassau Community College, SUNY Agricultural and Technology College at Farmingdale, SUNY College at Old Westbury, CUNY-New York, New York Institute of Technology, St. Joseph's College, and Suffolk Community College)

LICIL was originally funded in Fall 1996 with $2.8 million. The Consortium is headquartered at SUNY, Stony Brook (a Research-1 University), and includes 9 additional colleges and universities on Long Island: C.W. Post College, Dowling College, Nassau Community College, SUNY Agricultural and Technology College at Farmingdale, SUNY College at Old Westbury, CUNY-New York, New York Institute of Technology, St. Joseph's College, and Suffolk Community College. LICIL is attempting to develop an environment for interconnected learning in mathematics courses in mathematically based disciplines. It builds on pre-existing reform efforts and encourages faculty in mathematics and mathematics-based disciplines to collaborate with colleagues as well as implement new pedagogies.

Two levels of administration support project efforts. At the Consortium level, an Executive Committee acts as the institutional watchdog/organizer/supporter for Consortium-wide activities, such as forums and dissemination efforts. Each participating institution has committees to direct and support its activities.

LICIL uses two strategies to pursue its goals. First, it supports consortium-wide activities to generate professional development through collegial interactions. Second, it makes annual development awards to faculty for activities that advance LICIL goals, such as grants to faculty who work across departments on innovative approaches to teaching mathematics. To receive funding in subsequent years, faculty must show that they have involved additional people across department or institutional boundaries.

The project strengthens pre-existing efforts to develop new curricula, which are seen by participants as creating deeper conceptual understanding of mathematics. Most products are contextually and institutionally focused, so may not be appropriate for broad dissemination. Some materials are web-based.

Multimedia Mathematics: Across the Curriculum and Across the Nation (University of Nebraska, Lincoln, and Oklahoma State University, with Chadron State University, University of Tulsa, Tulsa Junior College, and Metropolitan Community College)

Multimedia Mathematics began operations in Fall 1996, with a reduced budget of $946,000. As a result, the University of Nebraska, Lincoln, focused on interdisciplinary efforts involving physics and biology, and Oklahoma State University on chemistry and engineering. Each is developing courses that apply mathematics principles and concepts in the other disciplines through the integration of interactive technology in laboratory-like classroom settings. The new materials are envisioned as part of existing courses, and students will have repeated exposure to mathematical applications through CD-ROMs and print materials.

Four co-principal investigators manage the project, three from mathematics and one from physics, with two at each campus. There is little involvement of other faculty or collaborative work across the campuses, in part a result of the limited budget.

The project has sponsored the development of several modules incorporating multimedia - such as graphing calculators, microcomputers, and CD-ROM technology-into pre-existing mathematics and other courses. In addition, one calculus-based lab course, Paperless/Paperlight Physics, is one of several lab sections required for all engineering students.

Conclusion

The mathematics initiative provides an opportunity for institutions of higher education to work together to reform undergraduate mathematics education so students are both more appreciative of the role of mathematics and mathematical thinking in academic and applied endeavors and more able to use mathematics. The program design builds on earlier success in calculus reform. The reform of the calculus included new curricula that embodied new pedagogical approaches, as well as formal and informal networks that facilitated dissemination of materials and pedagogy.

The mathematics initiative expands both elements, encouraging faculty to reform materials and pedagogy in a wide variety of courses, both within mathematics and in other disciplines. It also foster formal interorganizational arrangements that nurture exchange of ideas, materials, and approaches. Overall, the program presented grantees with a view that improvement in undergraduate mathematics entails a number of nearly simultaneous changes–in curriculum and in relationships within and across disciplines, as well as relationships within and across institutions. The seven projects funded as part of the mathematics initiative each approached the reform effort in a somewhat different manner, but most embraced the goal of improving student understanding of mathematics through integrating mathematics into other disciplines and incorporating other disciplinary perspectives into mathematics teaching. Overall, developing interdisciplinary links was most common with disciplines closest to mathematics, particularly engineering and the physical sciences. With a few exceptions, interorganizational arrangements were most easily accomplished across institutions that were also close, either geographically or in mission.

All seven projects are likely to sustain at least some aspects of the NSF-funded effort. Of all activities, new courses or modules are the most likely to be institutionalized. In addition, projects that developed intellectual communities and support for changed pedagogy and the use of technology seem likely to sustain such efforts. On the other hand, barriers to continuation exist, including university policies related to course listings and enrollment requirements, as well as the availability of necessary technology. When projects were able to overcome such barriers, they relied on strong leadership with knowledge of how best to influence policy, as well as existing policies, such as requirements for mathematical understanding, that supported the reforms that were undertaken.

NSF funded the seven projects to become "national models" for undergraduate reform. As such, project participants have paid attention to disseminating their efforts. However, the nature of the reform makes dissemination challenging. The greatest dissemination successes have been with curriculum and course materials, an area in which faculty have experience, but even in this arena, new technologies challenge old practice. Project participants are also interested in disseminating pedagogical approaches, and the processes they used to develop materials and / or relationships, but these topics present greater challenges.

DEVELOPMENT

The mathematics initiative is a direct descendant of the Course and Curriculum Development (CCD) calculus reform effort, which led to major changes in undergraduate mathematics education spurred by curriculum development and implementation. The successful strategy of bringing about extensive reform using curriculum as a key leverage point is central to the mathematics initiative, building on the experiences and relationships of many mathematics initiative participants, as well as NSF program staff. The initiative is designed to expand the traditional boundaries of the mathematics instruction in higher educational settings. The seven grantee consortia have approached this expansion in a variety of ways, although all are involved in some combination of the following activities:

- Designing and implementing courses;
- Designing and implementing instructional modules; and
- Implementing new pedagogies.

All mathematics initiative projects endeavored to develop new approaches to teaching mathematics, although there were differences in how they proceeded. Some started with broad ideas about new courses, and texts and/or manuals came later. Others followed a well-defined method for developing materials, focusing on specific disciplinary areas, sometimes with a systematic template and perhaps a publishing and dissemination strategy. In still other cases, projects provided guidelines for material and course development, leaving the process open. However, all projects shared the goal of developing materials that tied mathematics with other disciplines.

Projects differ both in the quantity and nature of materials they have developed, depending upon funding, as well as their intended emphasis. Further, curriculum development is an iterative process, so even within projects some materials are more complete than others are. And, as the later discussion of dissemination indicates, the "completeness" of materials influences the extent to which projects have focused on dissemination. After presenting examples of each type of curricular focus, we include a brief discussion of the quality of materials as judged by the content experts who were part of the monitoring teams.

Curriculum Materials

Mathematics initiative grantees interpret "materials" to include new texts, workbooks, homework assignments, projects, modules, and courses. We describe examples of all of these below.

Courses

Virtually all projects have developed and implemented courses linking mathematics to other content areas, most of which relate mathematics to the physical sciences and engineering. The connections between mathematics and physical sciences and/or engineering may be expected because the application of mathematical concepts is critical to mastery in these fields. Four projects designed and offered interdisciplinary courses involving mathematics and physical sciences or engineering departments. The University of Nebraska, Lincoln, SUNY Agricultural and Technology College at Farmingdale (a member of the LICIL consortium), the University of Pennsylvania (Midatlantic Consortium), and Dartmouth implemented such courses.

While there are fewer examples of courses that link mathematics and the social sciences and/or the humanities, projects found opportunities in these intersections as well. For example, one LICIL institution prepared an urban sociology course in which students analyze data about the community. In addition, two faculty members at Villanova (Midatlantic Consortium) created a new course in cartographiometry that crosses the disciplines of mathematics and geography and includes laboratory projects and computer technologies. The Indiana consortium developed several interdisciplinary courses, such as Finite Math for the Social Sciences; A Statistical Study of History; Mathematics, Art, and Aesthetics; and Mathematical Foundations for Speech and Hearing Sciences. Dartmouth has been particularly active in developing such courses as Music and Math, Geometry in Art and Architecture, Philosophy and the Mathematics of Infinity, and Applied Calculus in Medicine and Biology.

In addition to stimulating the development of interdisciplinary courses, the mathematics initiative served as a catalyst for the development of new mathematics courses intended to strengthen student learning in the mathematical sciences. Five projects have completed such courses:

1. Dartmouth developed and implemented a three-course sequence involving discrete mathematics, data structures, and algorithms;
2. the Indiana project implemented a new, project-based course in finite mathematics for first-year students, Mathematics in Action: Social and Industrial Problems;
3. Carroll College, a participant in the U.S. Military Academy's Intermath consortium, is restructuring its two-year sequence of mathematics courses for mathematics and engineering majors;
4. a LICIL institution developed a precalculus course that emphasizes application; and
5. Midatlantic Consortium project participants developed both precalculus and advanced mathematics courses.

The initiative also stimulated revisions of existing courses. For example, one Project Intermath partner, Texas Southern, which is a Historically Black College, revised its required algebra course, which had a high failure rate and was a significant barrier to graduation. The revised course is more project-based and less didactic.

Successful course development or revision began in one of two ways. One route to success began with faculty perception of student need. For example, members of the Indiana consortium noted that there had been a decline in enrollments in mathematics courses offered by the mathematics department related to the difficulty students were experiencing in them. Consequently, they decided to provide mathematics instruction in the context of a content area so students would learn mathematics and understand its relevance.

Another path built on existing relationships between individuals and / or departments, as in the cartographiometry course at Villanova, the many mathematics and physics, and mathematics and engineering courses, and the interdisciplinary activities at Dartmouth.

Modules

Several projects developed modules, intended to be stand-alone units of inquiry that can be integrated into a variety of courses, usually linking mathematics and some other discipline. Two projects, RPI (Links) and Intermath, focused almost exclusively on module development, and other projects mixed module development with full course development.

Both Project Links at RPI and the Intermath project are organized around module development. Project Links has developed or partially developed approximately 35 to 40 modules for introductory and advanced mathematics, physics, and engineering courses, and more than half have been used in the classroom. All Project Links modules are web-based, which reflects RPI's emphasis on technology and project-based, studio course orientation. Intermath's cornerstone is Interdisciplinary Lively Application Projects (ILAPs), which require students to use scientific and quantitative reasoning to analyze scenarios involving mathematics and one or more other disciplines. Typically, students work on ILAPs in small groups or pairs for 6 to 10 hours. The ILAPs are viewed as independent exercises that can be used in a variety of courses. Initially, each school in the consortium is expected to develop two ILAPs.

In addition to course development, faculty at Dartmouth designed modules related to population ecology, physiological ecology, and natural disasters and catastrophes, with each topic including 10 or more modules. The same project has developed modules on such topics as econometrics, calculus, and statistical inference, which are used to introduce mathematics concepts in a range of existing sciences and humanities courses. Most modules involve print materials, with an increasing emphasis on the use of technology.

Summary of Curricular Development

Although, as later sections of the report note, the mathematics initiative projects do not rely exclusively on course and curriculum development as a strategy for bringing about reform, their activity in this area is great. Four observations summarize the findings across projects.

First, the seven projects are developing a large and varied body of new courses and modules that have the potential to affect many students' learning of mathematical concepts. The courses range from ones designed expressly for non-mathematics majors to those designed primarily for mathematics students, as well as courses intended to serve students in other science and engineering disciplines that require a grasp of key mathematical principles and concepts. In addition to mathematics, physics, and engineering, the materials cover such diverse areas as biology, ecology, geology, history, literature, manufacturing and industry, music, and linguistics. The intended outcomes of new course/module development include significant changes in course content as well as in philosophy of teaching and learning. In several cases, these outcomes have already been observed.

Second, despite the broad array of disciplines involved in the initiative, the preponderance of the materials either enhance a mathematics course or support interdisciplinary links to physics, chemistry, and engineering. Project Links (RPI) and Intermath focus exclusively on the development of such interdisciplinary materials in the form of modules and projects. Except for the Indiana University consortium and Dartmouth projects, there are considerably fewer materials that connect mathematics with the social sciences and humanities.

Third, currently the majority of courses and modules focus on lower division classes taken by students in their first two years of college. For example, across the program, there are several new mathematics/physics, calculus, and algebra courses, including the multi-credit year-long mathematics and physics sequence at Dartmouth, designed for first year students. Virtually all the ILAPs developed within the Intermath project are designed to reform mathematics programs affecting lower division students, and both LICIL and Project Links focus primarily at that level. In contrast, the Midatlantic Consortium is developing several courses for advanced students, including Advanced Applied Mathematics, Geometry of Digital Spaces, and two courses that link mathematics and economics. Some RPI modules in probability and statistics and engineering are intended for students in more advanced courses. Nonetheless, the majority of currently available materials focus on early collegiate level.

Fourth, although most of the projects encourage faculty to develop course and curriculum materials using formats each developer sees as appropriate, three projects provide templates for materials development. The ILAPs, Project Links' modules, and the computer-based modules at OSU are each developed to an identified format. The use of a predetermined format facilitates materials development in the Intermath and Links projects.

Quality of Materials

The mathematics initiative's success in stimulating positive change in undergraduate mathematics education depends on the quality of the materials and pedagogy. The content specialist members of the monitoring teams assessed the quality of the materials and to some extent, the pedagogy they observed.

Content specialists visiting six of the seven projects reported that, in general, the materials they reviewed, either on paper or during classroom observations, were of high quality. A typical comment was made about Project Links: "The materials developed by Links are of high quality and illustrate concepts well." Similar opinions were expressed about the Dartmouth project and the Midatlantic Consortium, with reviewers commenting that materials met standards in their fields and would likely be valuable beyond the originating institutions.

Over time, as all seven mathematics initiative projects have become more sophisticated about developing new materials and courses, including paying greater attention to the appropriate use of educational technology, the quality has increased as well. Several observers noted that the materials are cutting edge in quality and use of technology. The content experts noted improvements in both the quantity and quality of modules, course readers, and interdisciplinary course syllabi between the first and second visits, which indicates that learning how to develop high-quality materials takes time and effort.

Despite the overall positive judgments about the materials, many content specialist reports contain recommendations for overall improvement in the initiative. Perhaps the most important suggestion came from a content specialist who noted that many of the materials being developed already exist. Other content specialists agreed that staff at the various projects should invest time to ensure that they are not duplicating earlier efforts.

Nonetheless, the general view of content specialists was that the projects were on the right path in developing materials to support the goals of the mathematics initiative program.

New Pedagogies

In many cases, curriculum change stimulated changes in how mathematical concepts are taught and learned, both within mathematics courses and in interdisciplinary settings. In others, however, changes in course content did not lead to changes in the pedagogy employed nor to "increased student appreciation of and ability to use mathematics." To change the teaching and learning environment, some participants argue, requires direct attention to faculty instructional practices to include the following pedagogical approaches:

- Teaching mathematics in the context of real-life applications;
- Increased use of projects and experiments;
- Increased small-group work and cooperative learning experiences;
- Increased emphasis on developing problem-solving skills rather than memorizing a body of information;
- Increased emphasis on interdisciplinary connections; and
- Integrating new technologies (e.g., CD-ROM, e-mail, calculators).

For most mathematics initiative projects, curriculum change was a key leverage point for ensuring the use of such pedagogy, but some emphasized the centrality of approaches to teaching more than they did the content of the curriculum. LICIL sees instructional practice as the key to reform in mathematics education. In this view, the goal is to increase cooperative learning, real-life applications, and project-oriented teaching in order to foster greater student engagement with mathematics and other disciplines that incorporate mathematical principles.

Other projects are explicit about the types of teaching encouraged by the curriculum changes they are making. For example, Project Intermath aims to change the culture of teaching mathematics, and Dartmouth frames its pedagogical mission as putting students at the center of the learning process:

- Students should take charge of their own learning;
- Students should be able to transfer knowledge from one context to another;
- Students should know how to find and use information for themselves; and
- Students should learn to construct their own knowledge rather than memorize and retrieve information.

The monitoring teams reported that three projects were implementing these pedagogical approaches. For example, Texas Southern, a member of the Project Intermath consortium, revised its algebra course to include more projects, less lecturing, increased real-life application, and increased group work. Observations of several LICIL project sites yielded many examples of new pedagogical practices in place, such as cooperative learning in chemistry laboratories, problem-solving in a course linking mathematics and physics, and a calculus course that connects mathematics to students' real world experience. According to one content specialist, "The methods that we witnessed both at Farmingdale [a member of the LICIL consortium] and at Stony Brook should promote active learning by the students and a greater appreciation of the interdependence of mathematics and other disciplines."

Other projects are also implementing new pedagogies. The Community College of Philadelphia developed an applications-based precalculus course that relies on student cooperative learning strategies and focuses on real-world problems and applications. At the University of Nebraska, the freshman calculus course is project-oriented and uses real-life applications (e.g., gathering heart-rate data from students in the class) in a computer-based laboratory.

The mathematics initiative strengthens preexisting changes in pedagogy in some projects, frequently with newly designed materials. For instance, Project Links at RPI develops interdisciplinary, multimedia, World Wide Web-based modules linking mathematics to science and engineering applications designed to engage students more actively. The modules are used in studio courses, conducted in classrooms configured with the necessary technology. Although the modules are newly developed, the concept of studio courses predates this grant. Similarly, the Dartmouth project is building on a history of active learning by students.

INTERORGANIZATIONAL ARRANGEMENTS

The mathematics initiative's goal of promoting "broad and significant improvement in undergraduate education" presents organizational, as well as intellectual, challenges to the projects. The organizational challenges stem both from the requirement that projects must have a "multi- or interdisciplinary...approach, and involve several undergraduate disciplines," and most projects believe their impact will increase if multiple IHEs are involved.

Projects are thus challenged to overcome typical university norms of isolation and individualism to enact key features of the initiative, crossing boundaries and fostering collaboration. To do so involves reaching out across institutions of higher education and across disciplines and departments within the IHEs, which require efforts that are often new to IHE faculty and administration. This section of the report describes the interorganizational arrangements that reach across IHEs, as well as the factors that facilitate or hinder their effectiveness. The following section will discuss the interdisciplinary arrangements.

Project Structures

The seven projects entail interorganizational arrangements, partnerships or consortia that connect multiple separate institutions with one another. Except for Dartmouth, which has informal arrangements with other institutions, the projects have formalized consortial relationships, although the effectiveness of the ties varies. This section focuses on the project structures that support the interorganizational arrangements, including how projects are organized and managed to achieve the goals of the initiative.

Most mathematics initiative consortia consist of a variety of types of institutions (e.g., major research universities, teaching colleges, technical colleges, community colleges). The composition of the consortia varies in geographical dispersion, ranging from all the institutions being in one region (e.g., LICIL), to one that is spread across the U.S. (e.g., Project Intermath). The differences in structure have implications for the ways projects are managed, and how successful they are in working across organizational boundaries.

The arrangements can be classified into three types:

- Coalitions or collaborations among IHEs, sometimes including an additional organization.
- Wheel-like arrangements, in which one institution is the hub and others relate to it individually. In one project, the points on the wheel are hubs for other institutions.
- Informal arrangements.

Coalitions and Collaborations

The largest number of projects are collaborations of a variety of institutions, generally with a strong lead organization. In general, such arrangements involve IHEs with different characteristics, contexts, and needs. LICIL, the Midatlantic Consortium, the Indiana project, and the University of Nebraska-OSU project are coalitions.

LICIL includes 10 diverse types of IHEs on Long Island, New York, led by SUNY, Stony Brook. LICIL has successfully structured its institutional partnership so members are able to access the resources, professional development, and expertise they need to be active members of the Consortium. The relationships across organizations result from awards to interdisciplinary faculty teams to support the development of courses, texts, problem sets, and other activities. Further, regular consortium-wide and other meetings, networks established through the Web, and newsletters provide avenues for frequent communication that reinforces the strength of the collaboration. In addition, the consortium has used other funding sources to create learning communities and teaching and learning centers on six of the ten participating campuses, which further support LICIL goals.

The Midatlantic Consortium includes four institutions in the greater Philadelphia area, each quite different from the others: a Research-1 university; a regional, church-related liberal arts university; a community college; and a professional association. Each participating IHE has developed materials, and some dissemination has taken place. Although at the start of the project each campus operated fairly independently, over time they have become much more interconnected. Important features of this consortium are regular exchange of ideas through scheduled meetings of the project leadership, cross-institution observations, and teacher exchanges. For example, a lecturer at Penn is teaching an applied algebra course at both Penn and Villanova. A faculty member from the Community College of Philadelphia teaches calculus to Penn students and to her students on the Penn campus (which is also a boost for the community college students, who are exposed to a different type of higher education). Other faculty also participate in planning. An example of the exchange of ideas that took place is as follows:

> A community college professor noted that she had informally asked for advice about how to approach a particular concept, and the entire executive committee offered suggestions, which she used in her course. Also, a physicist from Penn took the advice of the site visit team and attended one of her classes, where he reported he gathered some good ideas that he applied in his course.

The partnership of Indiana University at Bloomington, and Indiana University-Purdue University Indianapolis, (IUPUI), and, originally, six additional campuses of Indiana University is less successful in involving all institutions. The majority of the activity resides at the two larger campuses, IU Bloomington and IUPUI, with no participation at IU-Northwest or IU-East and some at IU Southeast, South Bend, and Fort Wayne. The project is structured as a collaboration, but the interorganizational relationships are weak. The two lead principal investigators have many obligations in addition to the project, which may be a reason for the lack of interaction across institutions. In addition, there has not been much support at the less involved campuses for more intensive faculty participation.

The partnership of the University of Nebraska (Lincoln) and Oklahoma State University (OSU) proposed including Chadron State University, University of Tulsa, Tulsa Junior College, and Metropolitan Community College as sites to implement new materials from the two larger university partners. Because of significant reductions in budget, the scope of the project was narrowed, and the two universities operate quite independently, working on parallel tracks, doing some materials development by mathematics faculty, with some emphasis on developing changes in classroom practices. After computer-based learning modules are completed and tested at each campus, the two campuses plan to share the modules.

"Hub and Wheel" Organization

Two projects are organized with a central institution that relates fairly separately to each of the participating institutions. Both have a well-ordered, systematic approach to developing materials that provides a template for development. Although the major relationships are from the central organization to separate participating institutions, the other participants have opportunities to interact at occasional meetings.

Project Intermath builds on a major curriculum reform initiated at West Point in 1990. The project's goal is to stimulate cultural change in the teaching of undergraduate mathematics by using a structured approach (ILAPs) to developing and using interdisciplinary student projects that require students to use mathematics concepts in appropriate contexts.

The project comprises a consortium of a variety of institutions with the Military Academy at West Point serving as the lead institution. As such, it convenes consortium members, training them to develop and use ILAPs, visits consortium member campuses, encourages faculty to participate and create ILAPs, reviews and edits ILAPs, and (with COMAP) publishes and disseminates them. The effort builds on prior collaboration among participating institution, input into the development of materials and planning for the future. The two co-PIs are the chairs of the Mathematical Sciences and Biomedical Engineering Departments.

Informal or Personal Relationships

One project, Dartmouth College, is implemented in a single institution, focusing on interdisciplinary work with physics, biology, and humanities. Rather than creating arrangements with organizations, Dartmouth works with individual partner faculty. According to Dartmouth representatives:

> Our team of investigators includes 47 faculty members...We also have 42 collaborators at other places who will work with us to see that our ideas, methods and materials are suitable for a wide variety of institutions.

For example, several courses were designed and co-taught by faculty from Union College and Vermont Technical College. The artist designer of "Patterns," a course in mathematics and art, visited SUNY/Oswego to gather ideas from a mathematics professor conducting a similar course. A Duke University professor of statistics was involved with a statistics module on inference for sample proportions. Also, a professor from North Carolina A&T, interested in discrete mathematics and computer science, contacted Dartmouth, reviewed materials, and then spent a week there developing a course. The course was first taught in Fall 1998, with materials under revision early in 1999. It is anticipated that NC A&T will have more students in this course than Dartmouth.

Summary

The interorganizational arrangements fulfill multiple purposes. Projects vary in the extent to which each purpose is salient, but overall, the arrangements help to:

- Create materials: In every consortium, at least two institutions are creating curriculum materials, either whole course or modules. Dartmouth, which is not part of a consortium, is working with individuals at other institutions to develop and pilot test materials.
- Ensure a variety of perspectives support materials development: The diverse types of IHEs within several consortia stimulate exchange of expertise. For example, community colleges gain access to the specialized knowledge that resides in R-1 universities, and the R-1 university faculty learn pedagogy from the teaching in community colleges. Examples of this type of phenomenon were evident in LICIL, Project Links, the Midatlantic Consortium, and Intermath. Such exchanges contribute to better materials development and improved opportunities for dissemination.
- Implement materials developed at the lead institution or elsewhere: The interorganizational arrangements have a dissemination as well as a development function. For example, in Project Intermath, ILAPs developed at West Point as well as at participating institutions are intended to become a regular part of the curriculum at the different institutions. Similarly, within the Midatlantic Consortium, both Villanova and Polytechnic Institute have adopted materials developed at the University of Pennsylvania, and Penn is considering adopting Statistics for Nursing Students under development at Villanova. Several Project Links partners are using R.P.I. materials, in part because large teaching loads and insufficient funding preclude the independent creation of materials.

Factors Affecting Interorganizational Arrangements

The mission of the mathematics initiative requires major changes for the participating institutions, both internally as boundaries across departments are penetrated, and externally, in the kind of interorganizational collaboration that are undertaken. Because formal interorganizational arrangements are not their usual way of doing business, the participating institutions varied in the degree to which they were interested, involved, and productive in those relationships. This section describes some of the factors that seemed to make a difference to the success of the undertaking. Some may be more strategically important than others, but each of the factors played a role in two or more projects. The factors, each of which is discussed below, are:

- Administrative support;
- Fit to the local context;
- Communication mechanisms;
- Leadership;
- The reputation of the lead organization;
- Geographic proximity;
- Prior relationships of the participating institutions; and
- Receptivity to learning from each other.

Administrative Support

Because the mathematics initiative requires forming relationships and operating in new ways, interorganizational relationships require support from administrators. Such support can overcome resistance and defensiveness from non-participating faculty. It may even enable projects to influence policies and procedures that are barriers to boundary-crossing collaboration. Initiative projects include several examples that demonstrate the importance of administrative support, including projects that received it and thrived, and those that did not and had problems.

RPI provides major support to Project Links, including in-kind resources, such as classrooms and equipment for an innovation that requires specific technological configurations, as well as intellectual support. The Deans of the Schools of Science and Engineering believe Project Links represents an experiment with considerable potential for the university more broadly, and the university president and provost strongly support the development of the web-based modules and share the systemic reform vision of the initiative.

An example of strong institutional support can also be found at Carroll College, a partner in Project Intermath. At Carroll, support has been both modest and effective, consisting of travel funds and small amounts of time, financial support, encouragement, and good computing and communication resources. Special support was also provided for the interdisciplinary arrangements, discussed in a later section. The administration at Texas Southern University also supported involvement in Intermath by providing release time to the coordinator, and a great deal of recognition and approval to those who participated.

In contrast, the low level of support from the administrative ranks at another project kept the project from correcting its rather insular approach. The administration did not see the initiative as special because university administrators see the mathematics department as a service department to other disciplines, mitigating any special support for interdisciplinary efforts. The administration saw even less value in working with an IHE in another part of the country.

Fit to the Local Context

As with successful curriculum change, institutional support was most forthcoming when the project was a good fit to the local context and meshed well with local priorities. For example, Dartmouth requires students to take at least one interdisciplinary course before they graduate, and the university provides start-up funds for some of the initiative-sponsored interdisciplinary courses because they fit the requirement. Similarly, a mathematical literacy requirement at Penn spurred the administration to support the types of reforms Midatlantic Consortium stimulated.

At Dowling College in the LICIL Consortium, the provost said the project fit well with the five-year strategic plan for the college, and that "the best part of the project is that it comes from the faculty." Similarly, Carroll College has a history of innovation and emphasis on teaching, which Project Intermath advanced. Texas Southern was also involved in curriculum reform so was an excellent environment for the project.

Communication Mechanisms

Interorganizational arrangements require adequate communication across participating institutions. Most projects developed strategies for enhancing communication, which serve multiple purposes. Sometimes procedures designed to facilitate management, such as the executive committees of the Midatlantic

Consortium and of Project Links, have other impacts. As an example, the Business Applications in Mathematics course at one IHE served as the model for the development of courses at two others. During the visit to one of these, the site visitors learned of a problem they were having with Excel. Earlier, we were told that faculty at the originating institution had solved this problem with a simple add-on to Excel.

Leadership

Active leadership and strong commitment of the PIs and consortium member coordinators is associated with broad involvement in a project and its interorganizational activities. A positive example is Project Intermath, where all three campuses that were visited have strong "champions." The following is an illustration from Carroll College:

> In order to understand the success of the project, it is important to understand its history and origin. Carroll College is a small and relatively isolated institution, but it has a reputation for its strong academic program and more recently, for its interests in educational innovation. In part this is due to the work of several entrepreneurial faculty who had become strongly linked to a network of mathematics educators, including those at West Point. Thus, the success of the project is due to their entrepreneurship, commitment, outreach, and energy. They are supported by the dean and several colleagues in these efforts, but the co-PI has been the driving force for the work, the collaboration with West Point, and with a Carroll College-led consortium of some small colleges in the region.

The strength of leadership must reside in the lead institution as well. For example, the leader at Stony Brook in the LICIL Consortium is widely touted as a major influence on the success of the project, functioning as a supportive and charismatic leader who sees himself as "pinning courage badges on to others."

On the other hand, another project has been hampered by the fact that the PIs are over committed with multiple obligations. As stated in the site report:

> The project lacks the presence of leaders who are able to maintain consistent contact with faculty, administrators, and evaluators. Additional leadership is necessary if the project is to maximize the ambitious efforts it has initiated.

Proximity

The projects include consortia that are both widely dispersed and within commuting distance of each other. Proximity is neither a necessary or sufficient condition for successful interorganizational collaboration, but it strengthens positive interactions when present and requires greater attention to relationships when it is absent. As the Midatlantic and LICIL projects illustrate, closeness facilitates the development of communication and other mechanisms that enhance interorganizational arrangements. However, without other supportive factors, proximity is not enough. The Indiana project, for example, involved campuses within a single state, and the arrangements among them were weak. And distance does not have to be a barrier to collaboration, as illustrated by Intermath, where the ties were strong. Intermath, however, had tight links among institutions based on the structured development process and pre-existing relationships among individuals at the participating campuses.

The Reputation of the Lead Organization

For the most part, the lead organization of each consortium is well recognized and prestigious. As "stars" in the academic universe, they draw other institutions to them. The reputation of the lead organization added prestige to the others, strengthened the credibility of the partnership in the eyes of administration and faculty, and fostered acceptance for reform. For example, a faculty member of the Community College of Philadelphia cited the "cachet" of being involved with the University of Pennsylvania as important in her ability to change her teaching of precalculus. SUNY Stony Brook, an R-1 university, is taking an interest in the other institutions in the LICIL consortium, which excites the attention of people in those IHEs:

> When partners mention they are involved with Stony Brook, or that they have worked on developing a course within the context of this grant, local PIs and professors report that "doors open" for them. In part, the reputation of Stony Brook impresses the campus administrators and deans. Further, the fact that the participants have evidence that these reform endeavors have worked elsewhere helps them make the argument that their own campuses should support them.

West Point plays a similar role in the Intermath project.

Prior Relationships Among Partners

While IHEs are autonomous organizations, many faculty members become well connected to their colleagues in other institutions, especially when they have a penchant for new knowledge or are interested in reform. A number of the mathematics initiative consortia were built on professional relationships established prior to the initiative, many dating from calculus reform activities. For example, the lead faculty at Carroll College and Texas Southern University were involved in calculus reform with faculty at West Point. The Dartmouth PI was able to reach out to colleagues in other institutions to be involved in development, field test, and implementation of new curricula materials. These prior relationships enhanced the potential for strong interorganizational arrangements.

Receptivity to Learning from Each Other

The diverse nature of institutions in a consortium can be a barrier to strong interorganizational arrangements because of differing missions and capacities, but it can also be a strength. Diverse institutions came to learn and gain from each other. For example, the University of Pennsylvania brought in a strong pedigree, but faculty from Penn learned instructional methods from the community college. At the same time, a community college instructor gained assistance from the university. Thus a factor that influences the continuing success of the collaboration is the degree of mutual benefit.

Summary

The projects funded by the mathematics initiative were largely able to reach across institutional barriers and develop strong interorganizational relationships. Further, such relationships existed between and among IHEs with similar purposes and characteristics and those with different missions. Relationships were strengthened through regular meetings, professional networks that existed prior to the project, the quality and reputation of the lead principal investigator and his/her institutional home, and open and mutually respectful communication. Although not all of these factors were present in successful projects, the projects that showed progress toward achieving the program goals of increasing student appreciation of and ability to use mathematics had more than one of these characteristics. In addition, projects that paid attention to the relationships among participating institutions and understood that they could learn from one another were more likely to be successful than those that viewed interorganizational arrangements as a one-way street.

INTERDISCIPLINARY ARRANGEMENTS

The mathematics initiative is designed to increase students' appreciation of and ability to use mathematics. As such, it encourages the use of mathematical concepts in non-mathematics course and examples and applications from other disciplines in mathematics courses. Consequently, the program embraces projects that are "multi- or interdisciplinary in approach, and involve several undergraduate disciplines." A principal strategy for achieving the integration of mathematics and other disciplines resulting in new materials and improved pedagogy was to develop interdisciplinary arrangements, both within and across participating campuses. In some ways, interdisciplinary arrangements may be even harder to implement than interorganizational ones, because the latter may focus on small groups of participating academics and not challenge the core operations of the institutions. Curriculum and teaching are the essence of departmental and individual faculty functions, and crossing the boundaries of departments may mean encountering cultural and bureaucratic conventions, as well as academic predispositions and loyalties.

The seven projects vary widely in how they implemented interdisciplinary arrangements. However, projects used two different types of approaches, collaboration and consultation. These approaches existed simultaneously within each project and across participating institutions:

- Collaboration involved multi-disciplinary teams working together to produce modules, units, or whole curricula that integrated mathematics with one or more of the other disciplines in the sciences, technology, business, the social sciences, and even the humanities. In at least one campus, interdisciplinary units were created that did not include mathematics. Only occasionally did collaboration involve team teaching, or teaching the material in two different discipline-based courses.

- Consultation typically involved providing input and/or review of materials to a faculty member who was trying to integrate concepts from his/her colleague's field of expertise. It sometimes included talking together about what concepts need to be taught in the unit or course.

As will be seen, these models are implicit in the operation of the projects, and all projects used both approaches.

Collaboration

Examples of collaboration drawn from each of the projects demonstrate the variety of approaches to working together across disciplines. Some approaches involve team teaching and cross-listing courses; others entail coordinated teaching of two courses; still others begin with collaborative development and are taught within a single classroom. Examples of each of these are included in the following section.

Team taught courses took two forms, and a single project could encompass both. For example, within the Midatlantic Consortium, the cartographiometry course was developed and taught by a geographer and a mathematician and cross-listed for both departments. At the same time, at Penn, calculus and physics are team taught, with the concepts coordinated and referenced within each class.

Another approach to cross- and inter-disciplinary collaboration involves faculty working together to design a single course. LICIL uses faculty development awards to encourage cross-disciplinary work, producing numerous products. For example, at Dowling College, faculty from mathematics and computer science are working together on a new operations research book for business students, while faculty from mathematics and aeronautics worked together to design an aeronautics lab for calculus. At St. Joseph's college, faculty in psychology and social sciences are working together on the unified statistics curriculum, while faculty from mathematics and economics are developing advanced economics and modeling modules. At Suffolk County Community College, faculty from accounting, biology, and mathematics are working together on using the Web to increase math awareness in business and science.

Project Links (R.P.I.) is characterized by interdisciplinary interactions, both structurally and substantively. Structurally, the project includes co-principal investigators, with one from mathematics and the other from engineering. Further, teams from mathematics and at least one other discipline, using a common template, develop all modules. Interdisciplinary teams meet and talk about ideas, coming to consensus about what should be in the module. Cooperation is very close, including exchange of classroom visits during discussion of topics related to the module. Such arrangements make it much more likely that both disciplinary perspectives will be represented in the materials developed.

At Dartmouth, interdisciplinary activities are based on a history of similar work on a smaller scale. The site visitors noted:

> We are very impressed with the quality of work undertaken, the interdisciplinary nature of the collaborations, the thoughtfulness given to the use of effective pedagogy, and with the enthusiasm and stamina of the faculty and graduate students. All materials are interdisciplinary and there appears to be real intellectual synergy among the involved disciplinary groups (e.g., humanities and math, earth sciences and math). The interdisciplinary work is very impressive. It is not a case of parallel and non-overlapping activities.

Carroll College, part of Project Intermath, has developed ILAPs that involve substantial interdisciplinary activities across many departments, including mathematics and biology, engineering, business, and health.

Consultation

Another model for cross- and inter-disciplinary work is consultative, rather than collaborative, in nature. Using this approach, faculty from one discipline ask colleagues from another about the concepts and examples that would be productive to include in a course. Frequently, the developer of course materials will ask colleagues to serve as reviewers, providing feedback from the perspective of their disciplines.

Site visitors pointed out an example, from the University of Pennsylvania, they believed could serve as a model for such consultation:

> Herman Gluck developed an advanced applied mathematics course in consultation with faculty in bio-engineering, computer science, and biomathematics, because students from those departments frequently enrolled in the course. As a result, not only is the course relevant to student concerns, but also professors from the other departments frequently sit in on classes and use what their students are learning in those classes. This type of collaboration can serve as an alternative or supplement to team teaching as a model for cross-disciplinary interaction.

Texas Southern University, a participant in Project Intermath, tends to follow the consultant model as it develops ILAPs, with faculty from non-mathematics departments, including transportation studies, business, and chemistry, consulting with mathematicians. The consultation approach also dominates the Indiana project, which has produced a significant number of courses in humanities and science; business, economics, and finance; biological and health sciences; and physical and engineering sciences.

Factors Affecting the Interdisciplinary Arrangements

Several factors appear to influence the degree to which interdisciplinary arrangements can work. When these characteristics are absent, the synergy is less likely to happen. Not surprising, a number of the factors are similar to those that facilitate interorganizational arrangements. The somewhat overlapping factors are:

- Institutional support and fit to local context;
- Leadership and training; and
- Methods to overcome cost barriers.

These, as well as the presence of the grant itself, resulted in energized faculty, with interest, energy, and enthusiasm mobilized to break down barriers and boundaries. For example, the faculty at Dartmouth have spent considerable energy reaching out to other departments, talking with administrators and individual faculty about particular possible projects. Building relationships one-on-one has taken considerable time, but those actively involved have seen the experience as among the most intellectually exciting of their careers. At Carroll College, the Intermath perspective has become remarkably pervasive, spreading to the social sciences and humanities and involving a critical mass of perhaps 20-25% of the faculty. The strongest, though non-quantifiable indicator of the strength of the faculty commitment is the enthusiasm they have for the process. People who are not directly supported by the project used words, which are uncommon among higher education personnel, like "passionately" and "totally committed".

Administrative Support and Fit to the Local Context

Interdisciplinary arrangements were highly valued by the administration of several of the campuses involved because the mathematics initiative fit with evolving priorities. As a result, the initiative received substantial support, including approval, recognition, financial assistance, and a reward structure that valued interdisciplinary efforts. Some examples are noted below:

- For the Midatlantic Consortium, the cross-disciplinary interactions on the three participating campuses are supported by the institutional climate on each campus. At Penn, a quantitative literacy requirement created the context for interdisciplinary interaction, enhanced by successful strategies used to develop the advanced applied mathematics course. Villanova's strategic plan calls for interdisciplinary work and faculty receive credit for such work in tenure decisions. The student-centered nature of Community College of Philadelphia increased efforts to innovate in mathematics.

- The Carroll College administration provides a great deal of approval as well as resource support to the Intermath Project, especially since it fits institutional priorities of improving curriculum and promoting innovative teaching. Although faculty members insist that their involvement is "bottom up" and grassroots, and does not come from an administrative mandate, the administration supports the project in several meaningful ways. The Dean and Vice President for Finance attended the retreat that began the ILAP development process, and provided support for it through a U.S. West grant. The college also allocated $2,000 to support the first summer's work to prepare ILAPs. The Dean asserts that the Intermath Project and concomitant curriculum reform "fulfills the mission of the college" with its emphasis on project-based learning and interdisciplinary learning. He is an advocate of experiential and active learning and feels it reflects "the typical way we should be teaching." He feels it also reflects the Catholic approach to the person as a whole being.

  The administration is aware that the new approaches require teacher change, and that some faculty are somewhat uncomfortable with change, especially those who are used to lecturing. The college supports a substantial amount of professional development. Faculty workshops on such topics as multiple sources for assessment, experiential learning, and use of technology occur twice each semester, and although they are voluntary, typically more than half the faculty attend. Given the number of requests for use of the computer labs in many departments, including courses in music and literature, the institution is considering funding a person to assist the integration of technology into the classroom.

- At several campuses in the LICIL project, faculty acknowledged that work on this type of the curricular initiative is given weight in the college tenure and promotion process. This was stated explicitly by senior faculty, and it was clear from conversations with junior faculty that they felt that participation in this program would be a consideration for promotion.

Leadership and Training

Two sources of leadership appear to inspire commitment to active interdisciplinary work. The first is the leadership and support provided by the lead institution to other members of the consortium. This includes motivation and persuasion, encouragement, training, consultation, review and editing. For example, Project Intermath has a rigorous quality assurance process for ILAPs, and the templates for modules in Project Links are important to all involved. And, in LICIL, the charisma and reputation of the principal investigator at the lead institution was an important factor in generating interest and excitement in the project. In two projects where such outreach and leadership did not exist, several proposed consortium member campuses had little or no interdisciplinary work.

In addition, once again, a campus leader or "champion" of the cause is a major factor in ensuring the success of interdisciplinary arrangements within the institution. Such champions articulated a vision for the work on campus and ensured that appropriate resources were available to those engaged in interdisciplinary activities.

Overcoming Cost Barriers

Interdisciplinary arrangements can be costly, which can be an overwhelming barrier to the fulfillment of the process. These costs include creating materials (needing time to talk and work together), obtaining resources and equipment, as well as implementing the courses. New courses received special funding, but when courses span departments, questions arise about the locus of support after the grant ends.

Some projects were able to overcome the cost barriers, largely through institutional support. A prime example is Dartmouth, which funds the start-up of interdisciplinary courses, so there is no issue of which department budget is responsible. Dartmouth obligated $2,243,000 as cost sharing for the initiative, and also provided funds to equip computer labs and renovate classrooms. Another example is Carroll College, which provides professional development and paid staff time to work on the materials.

Interdisciplinary materials that are supplemental can be absorbed into existing courses within departments. But whole courses that are interdisciplinary may continue to face funding issues. If fiscal support is not forthcoming, and if the courses do not prove to be successful with students, continuing interdisciplinary arrangements may be in jeopardy.

Summary

Interdisciplinary arrangements may be difficult to implement as they touch on the core operations of institutions of higher education. They are also the core of the initiative. Both collaborative and consultative arrangements were implemented in the projects, and were effective in the majority of them.

At least one project had difficulty in developing productive interdisciplinary arrangements. As cited in the site visitor report:

> Grant funds...have been used almost exclusively to support faculty and graduate students in the mathematics. Small grants have been made to four schools (or individuals) that are using or plan to use some of the...materials. However, there is minimal involvement in the project by faculty or graduate students outside of mathematics...Faculty from other disciplines had participated in discussions leading up to the proposal, but those that we talked to were totally unaware of the activities that have been done thus far with grant funds.

The factors associated with successful approaches to interdisciplinary arrangements included fit with the local context that generated administrative support, leadership and training, and methods of overcoming cost barriers. When such characteristics were present, faculty focused their energy on developing and implementing interdisciplinary courses.

DISSEMINATION

According to the grant announcement, "projects supported through this initiative are expected to serve as national models." Consequently, dissemination is critical to the success of the effort. As projects have completed course and curriculum materials, as well as structures and processes that support collaboration across institutions and disciplines, they have focused increasingly on dissemination. All the mathematics initiative grantees have made progress on dissemination activities over the course of their projects, but they vary considerably in what they choose to disseminate.

When we visited sites during the 1997-1998 academic year, dissemination was generally in its early stages, and in most cases, the PIs described their dissemination activities largely in terms of spreading mathematics initiative outputs within the institutions involved in the consortia. The 1998-1999 site visits revealed both increased faculty knowledge and a broader set of activities related to dissemination. In addition to internally focused activities, projects were disseminating outside their own boundaries. Further, dissemination is not limited to instructional materials, but also includes disseminating ideas and processes. In sum, projects disseminated:

- Tangible products, including courses, modules, and other instructional materials;
- Ideas, such as the use of discipline-based applications to teach mathematical concepts, cross-department or interdisciplinary team-teaching; and
- Processes, including modeling interdisciplinary collaborations for new faculty.

Not surprisingly, projects have focused the bulk of their dissemination efforts on materials.

The seven projects approach dissemination in different ways. For some, the consortium itself represents the major mechanism for disseminating instructional approaches and materials. Dissemination occurs through the development of collaborative relationships across disciplines or departments and across institutions, as well as through consortium-wide workshops and conferences. For many of the projects, the part- stitutions within the consortia serve as pilot sites for one another's courses and modules. For others, dissemination was more national.

Most projects view traditional publication as a major avenue for disseminating their materials. Although several projects are pursuing commercial publication, others are relying on the growing role of the Internet as an alternative means of making their materials widely available. Further, the projects use workshops, conferences, newsletters, and publishing articles in journals to spread information about their products, ideas, and processes to individuals and institutions beyond the institutions involved in the consortia.

The Role of Consortia in Dissemination

Six mathematics initiative projects are organized into consortia, which promote interdisciplinary collaboration within and across partner institutions. In addition, consortia serve to disseminate pedagogical reform and curricular materials among the participating institutions. For example, the principal investigator of LICIL distinguishes the mathematics initiative from curriculum projects by emphasizing its goal of changing the instructional practices of faculty members across all the participating institutions. The consortium serves as a "learning community" to advance this goal by sharing practices. Similarly, Project Intermath's objective is to change undergraduate mathematics instruction by integrating the curriculum within mathematics and across disciplines. Consequently, each participating Intermath institution is responsible for developing two ILAPs, which will be shared within the consortium and beyond.

Both projects include mechanisms for supporting dissemination. The Executive Committee at LICIL is responsible for dissemination and publicity, encouraging others to choose from the materials that are being developed. The principal investigator used two images to convey his sense of how materials would be adopted–a food court and a play book. Both embody a view that there are a number of ways to put together a strong program, and individual faculty members make the choices. At this point, however, the extent to which the materials are useful elsewhere is not known. One content specialist noted that although there is broad potential for disseminating materials within the consortium, materials developed by a team at any single participating institution have been used only on that campus and may not be directly transferable to other institutions.

Project Intermath provides assistance to interdisciplinary teams at participating institutions as they develop ILAPs. The first venue for dissemination is consortium members, and there is evidence that ILAPs are being developed and used in consortium institutions.

Other projects are also engaged in dissemination within their consortia. For example, a colleague who did not originate the materials has taught the mathematics/physics course developed at the University of Pennsylvania (Midatlantic Consortium), and non-developer faculty members have also taught several other courses. While Dartmouth College is not part of a formal consortium, individual faculty members are working with faculty members at other institutions to co-develop and/or pilot test courses and modules, including North Carolina A&T University and Vermont Technical College.

Dissemination within the consortia seems to be more difficult when one or two universities play a dominant role, and others are less engaged in and informed about the project. In one project, most of the materials developed are created by a small number of faculty members at two institutions. Other members of the consortium are expected to serve as field test sites, but to date, no materials have been tested at other institutions. The content specialist believes that more groundwork should be laid if involvement is to be broadened. Similarly, a content specialist who visited another project expressed concern that faculty at the smaller campuses were left out of the course development process and poorly informed about the project.

External Dissemination

Although projects disseminate ideas and information about processes, their major efforts are devoted to disseminating the materials they develop. Consequently, publication is the most widely-used dissemination approach. In addition, mathematics initiative projects make presentations at professional meetings, publish newsletters, conduct workshops, and seek partnership arrangements to spread their ideas

Publication

Traditionally, NSF has encouraged developers of course and curriculum materials to seek publication as the major approach to dissemination, and the mathematics initiative projects are devoting considerable energy to this dissemination strategy. However, in the current environment, publication takes two forms: traditional approaches through academic presses, self-publication, and professional societies; and alternative methods, primarily the use of the World Wide Web.

Traditional Publication

Dartmouth is one of the few sites that is concentrating on dissemination by academic publishers. It conceived of its modules as a series of 20 to 30 inexpensive, application-driven paperback books designed for use either with standard texts, as independent reference materials for students, or as groups that could be combined for interdisciplinary courses. For the past two years, project leaders have actively sought publishers as a top priority, and they have had serious conversations with a number of publishers—some of whom have visited the campus. The content specialist who reviewed the materials, however, is concerned that packaging the materials for traditional publication may be difficult because of variation in their size, scope, and intent.

Several projects have found publishers for textbooks. These include college algebra texts (Project Intermath and University of Nebraska, Lincoln-Oklahoma State University), as well as interdisciplinary texts written by faculty from Indiana University (a supplement to introductory biology and materials that use mathematics for business, economics, and finance courses) and the Midatlantic Consortium work in business and mathematics. A number of additional course texts are in the process of being completed within both the Indiana and Midatlantic projects.

Project Intermath has a potentially strong mechanism for publishing and disseminating its materials. COMAP, the Project Intermath grantee, is responsible for disseminating the ILAPs developed by the consortium. It published the ILAPs developed at West Point prior to this grant. The Mathematical Association of America has also published a collection of ILAPs, including two designed at Carroll College, a consortium school.

Alternative Forms

Many projects are exploring the World Wide Web as an alternative or complement to more traditional dissemination methods. For example, a computer scientist at SUNY, Stony Brook (LICIL) revised his introductory text through the mathematics initiative grant and made it available online. He prefers to use the Internet rather than working with a traditional publisher because the field changes so quickly. Similarly, modules developed at RPI for Project Links have a multimedia format, using the web, browsers, text, and applets (using Java). Faculty in the Midatlantic Consortium have established an on-line journal housed at Pennsylvania, called *Journal of Online Mathematics and Its Applications*, which they anticipate will serve as a major vehicle for dissemination. Three other projects also have some materials on the web, and, increasingly, the projects have come to realize that the Web can be a valuable dissemination tool.

Although the Web represents a potentially powerful means of dissemination, an approach dependent on technology can limit the audience to be reached. Project Links discovered that one institution in its consortium indicated that students would be charged a technology use fee for using the computer laboratory to gain access to the modules. Most project participants believe that limits to dissemination that stem from technology are likely to dissipate as more institutions and individuals gain access to it.

Workshops and Other Types of Dissemination

Although projects commonly use workshops within the consortium to build enthusiasm and promote collaboration, only a few are currently using them to disseminate information beyond their boundaries. Dartmouth has been quite active in this respect, and has held workshops in Mathematics-Philosophy-Literature and Mathematics-Art, both of which were oversubscribed, as well as a workshop on Mathematics in the Earth Sciences, Biology, and Engineering. Colleges were encouraged to send two faculty members, a mathematician and a non-mathematician, to encourage collaboration at adopting sites. Another example comes from Indiana University where a faculty team scheduled an event to share its work with other colleges in the region. The team hopes that this will be a prototype event for the entire project.

Projects also use a variety of other mechanisms to publicize the mathematics initiative. SIAM, a member of the Midatlantic Consortium, has a large membership of mathematicians in industry as well as university scientists and engineers who use mathematics. It has devoted newsletter space and annual meeting workshops to the project, and the Midatlantic project and Dartmouth have both had articles published in the SIAM newsletter. Journalism students at Indiana University produce a newsletter that provides IU campuses and others with information about course development and other project activities.

In addition to presenting workshops focused specifically on the mathematics initiative, faculty members representing all seven projects have made presentations about their projects at national professional association meetings and conferences.

Disseminating Ideas

The mathematics initiative builds on a very large idea-that students' learning of mathematical concepts will be significantly improved when those mathematical concepts are integrated into students' other disciplinary educational experiences. The projects embrace the general idea, but vary greatly in the actions they see as the best way to integrate mathematics across the curriculum.

Communicating about success allows projects to share ideas about how to achieve the initiative's goals. The projects rely upon several tools to communicate the underlying ideas of the mathematics initiative, including workshops for members of each consortium, initiative-wide conferences, invited presentations at other IHEs, and publications about the mathematics initiative in *SIAM News* or *The Journal of Online Mathematics and Its Applications*. As the numbers of involved faculty increases, the opportunities for greater awareness increase as well. At Dartmouth, for example, up to 50 faculty members have been involved in developing and teaching interdisciplinary courses and/or course materials, and project faculty believe the climate for interdisciplinary learning has been significantly affected by the Initiative. Dartmouth's size facilitates achieving a critical mass of participating faculty in mathematics and across the campus, but the value of having a critical mass was echoed across several other initiative projects as well.

Several of the projects capitalized on their evaluations to publicize the effectiveness of the ideas embedded in their materials, courses or modules, collaborations, and other activities. Project Links has a sophisticated evaluation design that includes assessment of student attitudes in instructional contexts as well as a multi-layered review process that attends to adherence to the Project Links template; a rigorous content review by faculty members in mathematics and other relevant disciplines from other institutions; and an educational technology review. The Midatlantic Consortium used its evaluation findings in developing a thoughtful six-point dissemination plan to ensure that the project would use the appropriate avenues for circulating its ideas both within and outside its group. In addition to pre- and post-attitude and content knowledge surveys of students, the Dartmouth evaluation is following students who have participated in one of its centerpieces, a multi-credit Interdisciplinary Math and Physical Science course, to learn about their perceptions after they have taken subsequent mathematics and physical science courses. In the best cases, projects are using evaluation data on a regular basis to ensure that their collective work not only has sufficient technical and content merit to satisfy internal standards, but to make evident to non-developers and others that these efforts lead to success with students.

Two projects, LICIL and the Midatlantic Consortium, are developing guides to assist others in developing similar mathematics reform programs. LICIL's proposed "Play Book" and the Midatlantic project's "Lessons Learned" monograph are efforts to summarize and reflect on the issues confronted by those projects as they worked to achieve the goal of reforming undergraduate mathematics education. As such, the documents are likely to appeal to individuals in IHEs who are embarking on similar reform efforts.

The dissemination of ideas is important because faculty members develop and teach courses that reflect their own areas of expertise and interest, and materials developed for a course, or even the course itself, may be more idiosyncratic than transportable. The ideas, however, of using engineering- or physics-based applications to teach calculus concepts, or of working with faculty in allied disciplines who also expect students to understand mathematical principles, or of illustrating the intellectual history and connection between mathematics and other disciplines, are quite transportable. Dartmouth faculty recognize that transfer of ideas in and of itself is quite worthwhile, noting that specific applications for mathematics are less germane for the humanities courses, for example, than are some of the larger ideas such as chaos theory, or the concept of time, or infinity.

Dissemination Challenges

Although the projects have made significant progress in developing and disseminating materials, courses, other products, and ideas, a number of challenges remain. Most faculty understand that developing new materials or courses or other strategies for teaching are essential elements of their professional responsibilities. The increased demands that come with collaborating with others on these activities mean that the work is somewhat harder, and certainly more time consuming. An often-repeated comment from faculty members was that they were not as far along in the dissemination phase as they had hoped. Typically, the slower pace reflected the time and effort it takes to develop high quality materials and courses, as well as establish effective collaborative relationships across departments and institutions. Additionally, faculty members are often caught up in the regular routines of teaching; once the course has been completed, the energy and momentum to continue to develop materials for others to use elsewhere may wane.

Another issue is the anticipated shelf life of new materials and courses. Especially for web-based modules and materials, faculty members are concerned that their work may have only limited utility as new learning technologies are developed. A related issue is whether products being developed will be as widely accessible as the developers might hope because the hardware and software demands are so high, and the technologies continue to evolve so quickly.

One of the most critical problems, though, is that while faculty members are more accustomed to the development and writing tasks, they are less familiar, as a group, with the world of publishing. A number of faculty have experience in writing textbooks, and most have experience in submitting articles to professional journals, but these experiences have not prepared them for identifying and courting publishers for interdisciplinary materials. Further, the range of materials is so varied in scope, sophistication, and potential application that finding a single publisher may be a more difficult proposition than it would be for a single volume.

Mathematics initiative faculty participants raised two other concerns about publishers. First, publishers identify their markets as quite discipline-specific, which means that finding a publisher willing to experiment with interdisciplinary materials is challenging. Second, the educational publishing market has become more competitive, and the number of academic publishing houses continues to drop as a result of business mergers.

In addition, dissemination of some course materials developed through the initiative may be limited by the nature of their content. For example, although every observer noted the high quality and creativity of the cartographiometry course, the number of IHEs with strong geography departments is small, thereby limiting potential adoptions. And, even within consortia, differences in the prior education of students may require changes in course and curriculum materials. Project Intermath, for example, envisioned the first stage of dissemination as existing within the consortium, but one content specialist noted that ILAPs produced at West Point for West Point students are likely to require modification for participating institutions that serve less well-prepared students. It is likely, then, that products that receive the widest dissemination are the ones that can be most readily modified to fit the setting in which they are to be implemented.

Product dissemination is perhaps easier than disseminating ideas and processes for the widespread adoption of a philosophy about student-centered and interdisciplinary learning. More than a decade after the start of the calculus reform movement, calculus reform has not been universally embraced. Even so, there is ample evidence that approaches reflecting the mathematics initiative philosophy have generated meaningful changes in their institutional settings, and in these projects, dissemination to the host institution is a primary goal.

As the mathematics initiative projects enter their final year of funding, they face the additional challenge of trying to complete materials and continue their efforts to share their efforts with others. It is already clear, however, that several projects have built a solid foundation and that dissemination is likely to continue.

INSTITUTIONALIZATION

NSF provided funding for seven projects to develop national models to reform undergraduate education in mathematics. From one perspective, then, examining the extent to which IHEs that received mathematics initiative grants institutionalize the activities and approaches developed through NSF funding may be unnecessary. A contrasting perspective argues that institutionalization, or what remains after the grant is concluded, is as important as dissemination. From that perspective, NSF has made a significant investment in a limited number of institutions, and there should be some footprints of that investment. In addition, one could argue that a national model must be such that adopting IHEs can bear the costs and implement the program from normal funding sources. In this view, NSF's investment is in development, and continuing implementation must rely on local commitment.

This section addresses institutionalization in two ways. First, we look at what is likely to endure that bears the mark of the mathematics initiative. Second, we analyze the factors that seem to support institutionalization.

What is Likely to Remain

The material outputs of the program are the most likely to be institutionalized, just as they are the easiest content for dissemination, because IHE faculty define themselves in their instructional role, and course revision is part of that role. Consequently, across the projects, examples of the continuation of reform courses, or the inclusion of modules within courses, are most prevalent. In addition, some projects have stimulated the development of interdisciplinary and cross-institutional relationships that seem likely to endure. Even with the successes, however, challenges to institutionalization are great, and the discussion of those challenges will be used to lay the groundwork for the discussion of the factors that seem to support institutionalization.

Courses and Course Materials

Although at most participating institutions it is too soon to judge whether courses and course materials developed through the program will remain, there are indications that many will become permanent features on the campuses. Indicators of high potential for institutionalization include a course (or materials) that has been taught multiple times, has been taught by faculty who were not involved in the development, and/or new requirements that include the course.

Five projects have strong potential to institutionalize new courses or materials, supported not only by participating faculty but also by the IHE. The ambitious scope of interdisciplinary courses at Dartmouth is likely to yield a large number of courses that become a regular part of the curriculum, and both the University of Pennsylvania and Villanova (Midatlantic) have offered the same cross- and interdisciplinary courses at least three times, with the Penn course taught by faculty not involved in the development. One participating Indiana institution has changed the honors program with an approach fostered by the mathematics initiative, and another has changed the nature of courses, including a course in psychology and statistics. Carroll College, from the Intermath project, has implemented a new mathematics curriculum, and the modules developed by Project Links seem to have a high potential for continuation.

Teaching Strategies

Changes in teaching strategies are associated with course and curriculum change, and are likely to continue along with the reformed courses. In addition, two projects, LICIL and Project Links have made changes that support new pedagogical approaches, no matter what materials are used.

LICIL exemplifies institutional change that focuses on pedagogical issues. A number of participating LICIL campuses have adopted policies that support continued attention to instructional practices that foster problem-based, student-centered learning. For example, instructional practice is an issue in tenure and promotion decisions, and the use of cooperative learning techniques is both widespread and lasting.

The approach at RPI reflects the institution's longstanding commitment to ensuring that it remains at the cutting edge of technology use. As a result, RPI's building renovations resulted in many classrooms appropriate for "studio courses," which are problem-centered, use modules, and require new ways of teaching.

Relationships

The mathematics initiative encourages interdisciplinary and interorganizational relationships as means to achieving program goals. But for some projects, the relationships seem enduring. At Texas Southern University, for example, site visitors noted that collaboration across departments was deep and had the earmarks of being lasting. And, although difficult to develop, the cross-institutional ties within the Midatlantic Consortium seem likely to last because faculty from participating institutions report learning from one another and exchanging faculty. However, the site visitors were concerned that when regular meetings of the cross-campus executive committee for the project cease, the informal interchange that supports the relationships will also end.

Challenges to Institutionalization

Even in sites that are likely to be successful in institutionalizing elements of the mathematics initiative, there are barriers that must be overcome, and in others, the barriers are insurmountable. Most challenges to institutionalization stem from policies and procedures that do not easily accommodate cross- and multi-disciplinary courses. A few challenges result from faculty attitudes about what constitutes appropriate educational experiences for students.

University policies that require minimum enrollments are likely to limit institutionalization. At Indiana, enrollment in a number of interdisciplinary courses is so low that it is doubtful they can continue without outside funding. The low enrollments in many of the new courses demonstrate student skepticism about the value of interdisciplinary courses. They fear, site visitors were told, that graduate and professional schools would not recognize the courses and penalize them for enrolling. Some faculty, who express concern that the new courses will not "cover" sufficient materials, reinforce such fears.

Other policies may also impede institutionalization. For example, a number of universities require that each course have a departmental "home," which creates a disincentive for faculty to collaborate across departments because when courses are cross listed, issues arise about which department will receive credit. Dartmouth has worked through the problem, but other campuses are still struggling to accommodate new courses within the existing system. And, although the Community College of Philadelphia was the only institution among the IHEs in this evaluation affected by a union contract and policies defining a "full-time" load, such requirements may impede the institutionalization of the highly valued precalculus course.

The challenges to institutionalization are great, so those courses and practices that become part of the "normal" way of conducting business require active support. The next section examines the factors associated with successful institutionalization.

Successful Institutionalization

Almost all projects involved in the initiative were successful in ensuring continuation of all elements at all campuses. Successful implementation seems the result of actions taken by project staff and the contexts in which the projects are housed. These combine to:

- Build faculty and administrative commitment; and
- Encourage policy and fiscal investment.

The potential for institutionalization begins at the start of the project, and leaders who attend to building commitment to project goals and activities lay the groundwork for success. Commitment leads to investment, of money and through changed policies that support the work of mathematics reform. Finally, institutionalized policies and programs receive ongoing policy and financial support from the host organization.

Commitment

The process of building commitment to the project and the activities it sponsors began during the writing of the grant proposal. In every case, project leadership created plans that started with relationships previously established with colleagues at their own and collaborating IHEs. With few exceptions, the pre-existing relationships ensured that a core group shared a commitment to project and program goals and had some degree of agreement on appropriate ways to achieve those goals.

Once funded, project leadership faced the need to broaden involvement in the project. Projects approached this task in a variety of ways. A number explicitly worked through networks and relationships established earlier. For example, Carroll College faculty members were interested in the initiative because they had prior collaborations through the calculus reform network with the leadership of Frank Giordano, whose text is used on the Carroll College campus and others at West Point. Similarly, at Stony Brook, many of the leaders at the participating campuses had worked together to reform calculus, co-authored texts, and continued to enjoy partnerships over the years.

In addition, projects encouraged broad involvement to ensure its impact. For example, from the beginning, Dartmouth proposed to involve faculty from within and outside the mathematics department. The core of the approach is the development of modules by teams that were to include at least one professor from a discipline other than mathematics. In addition, Dartmouth created a review panel of an equal number of colleagues from other institutions.

Other projects used inducements to spread participation. The Carroll College dean allocated funds to inform faculty about ILAPs, starting with a retreat funded from other sources. LICIL provided faculty development awards.

Equally important to building involvement and commitment from faculty was gaining the commitment from administrators. Such efforts to expand involvement were most successful when project activities fit with the local context. The Midatlantic Consortium's offer to work with faculty from other disciplines to help them meet the quantitative literacy requirement at Penn is one example of gaining commitment due to local circumstances. Similarly, Dartmouth's traditional support for interdisciplinary studies and RPI's interest in maintaining itself at the cutting edge of technology use made fertile ground for spreading commitment. At SUNY-Stony Brook, the president is a well-known advocate for reforms in undergraduate teaching.

When the context was less supportive, administrators were apt to leave the project alone. Such passivity may not have hurt development efforts, but it limited the extent to which projects could influence those who were not directly involved.

Although the major purpose expressed by project leadership for seeking broad involvement was to increase project impact, involvement led to commitment, which, in turn prepared the institution for continuing project-sponsored activities and approaches.

Investment

Once faculty and administrators became committed to project goals, they invested time and energy to achieving them. Both fiscal and policy investments support institutionalization.

The information we collected on materials development demonstrates the enormous time and energy faculty members devote to the project, reflected in the quantity of materials produced. Two questions about the investment of individual time arise. The first is whether faculty members can (or should) sustain the high level of activity required to produce new course materials while continuing their other duties. The second relates to the materials that were developed and asks whether the IHE will support their use over time, even if they challenge existing policies and procedures. When faculty reported that their administrators were making changes in the structure of the university, site visitors viewed this as foreshadowing potentially sustainable activities. Examples of this include Dartmouth requiring interdisciplinary courses and considering new sequences of required study. Similarly, LICIL's changing tenure policy to increase emphasis on teaching and collaborative activities also holds promise for the resilience of the reforms.

The absence of administrative support impeded implementation and also institutionalization. For example, a key administrator at OSU, while not disapproving of the efforts undertaken as part of the grant, did not see its value to the university. In his eyes, mathematics is a service discipline, so should always be involved with other departments, and no special efforts or activities are needed.

These lukewarm acknowledgments are far different from the cordial overtures made by administrators who believed that the program fit institutional goals and was worth investing in. Administrators at institutions involved in two projects told us the project was directly in line with the universities' strategic plan.

In other cases, the financial support from the university explicitly reveals the investment made to the project. Dartmouth provides an example of such investment:

> According to Dartmouth's Grants and Contracts office, Dartmouth has obligated $2,243,000 as cost sharing for the mathematics initiative. According to Project documents, a large portion of the expenses for faculty, undergraduate assistance for courses, and graduate assistance in the form of stipends and tuition are covered by Dartmouth. Dartmouth funds have been used to equip computer labs and renovate classrooms.

The key element in building investment is linked to how the administration is involved and the extent to which they are able to view initiative activities as those that will improve the campus overall. Administrators have given split course credit for interdisciplinary courses, required interdisciplinary courses, and considered changing course requirements because of the initiative (Indiana and Dartmouth). Other institutions link tenure and promotion decisions to reformed pedagogy. Such changes in policy support the goals of the mathematics initiative and support continued attention to reform of undergraduate mathematics.

Summary

Footprints of the mathematics initiative are likely to be found in many of the institutions involved in the program. Most commonly, courses and pedagogy will be different from what existed before the grant and will exemplify at least some aspects of what is needed to increase student knowledge and appreciation of mathematics and its relationship to other disciplines. Relationships among faculty across disciplines are also likely to be sustained in many places, and in fewer, relationships across institutions will remain strong.

Sustained attention to reform of undergraduate mathematics education was most likely when projects built broad support by involving large numbers of faculty. Further, administrative support was essential and was most easily gained when project activities fit with institutional goals, but could be stimulated by demonstrating success. Administrators showed support by working with faculty to change policies toward course credit, cross listing of courses, requirements, and promotion and tenure.

CONCLUSION

NSF created an ambitious and challenging agenda for special initiative, Mathematical Sciences and Their Application Throughout the Curriculum (MATC). It was designed "to promote comprehensive improvements in undergraduate education that lead to increased student understanding of and ability to use the mathematical sciences" (NSF, 1997). The grant announcement indicated that NSF expected projects funded through the initiative to create course and curriculum materials and work across disciplines and institutions. Such activities were designed to accomplish comprehensive improvements that "serve as national models for improving student understanding in the mathematical sciences, encouraging better integration of mathematics into other disciplines, and improving instruction in the mathematical sciences by incorporating other disciplinary perspectives." As the projects approach the end of NSF funding, it is appropriate to ask questions about the extent to which NSF realized its goals.

As this report indicates, most projects successfully put in place the elements NSF noted as parts of comprehensive improvements in undergraduate education. They developed course and curriculum materials, encouraged changes in pedagogy, facilitated inter- and cross-disciplinary relationships, and encouraged arrangements that strengthened ties between institutions of higher education. And more than half created enthusiasm for reform among faculty and administrators not originally associated with the grant.

Questions remain about how well the projects will serve as national models. If the analysis is confined to the course and curriculum materials, then the conclusion is largely positive. Most projects developed materials that are being disseminated and have some promise of being adopted elsewhere. And, the approaches to development involving collaborative or consultative relationships across disciplinary bounds are potential models for others. Similarly, structures, including those that foster frequent in-person interaction, were used by projects to foster interorganizational collaboration and may be adopted elsewhere.

At this point, however, it is difficult to point to a project and say to the world of higher education: "Go to X University if you want to see what comprehensive reform looks like." This may be a result of the length of time it takes to bring about reform, or it may stem from the fact that IHEs in the United States vary greatly in their context, organization, mission, and student characteristics.

On the other hand, the mathematics initiative has involved large numbers of faculty and administrators in a conversation about what mathematics education at the undergraduate level should be. That conversation is likely to yield increased attention to the goals of the program. The mathematics initiative built on the calculus reform movement, which brought together widely dispersed networks and faculty from a variety of institutions who developed relationships that now serve broader goals. The initiative has expanded the networks, advanced the conversation, and built the base for the next stage of reform.

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