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Interconnected Quantitative Learning At Farmingdale State

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In recent years, the economy of the Long Island region has been completely transformed. What had been, since the late 1940s, a base of a handful of large defense contractors such as the Grumman Corporation has changed to a large number of relatively small to medium sized high-technology corporations. Simultaneously, Farmingdale State University of New York has itself undergone a total change in its mission and the underlying academic culture. The college has evolved from a two-year agricultural and technical college to a four-year university college of technology with eighteen baccalaureate programs and twelve associate degree programs. Most of these programs are in the areas of applied sciences and technologies relevant to the current Long Island economy. Farmingdale State is located on Route 110 on the Nassau/Suffolk County border in New York, about 25 miles east of New York City. The area is a hub of high-tech industries on Long Island known as the "Route 110 Corridor." The college is the home of the Broad Hollow Bioscience Park, which is viewed as the centerpiece for the many high-tech facilities found within the Route 110 Corridor.

As a four-year College of Technology within SUNY, one of the official goals at Farmingdale State is "to provide students with a broad academic foundation which includes an appreciation of the interrelationships among the applied sciences, technologies and society." Although the College's focus is on the applied sciences, we also have programs such as liberal arts, business, nursing, and dental hygiene, among others, which require us to serve a wide range of students. From the perspective of the mathematics department, this requires us to provide a meaningful mathematical experience to all students, regardless of major, which relates mathematics to the real world in a way that resonates with and draws upon the interests of the students. To this end, in all courses we include student projects and assignments that go beyond symbol manipulation and template problems. We present topics within

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the context of an intellectually stimulating problem, model, or analytical challenge.

In order to succeed at its new mission in a changing regional economy, Farmingdale State had to undergo a major restructuring which included a fundamental change in the campus culture. As we faced this challenge of totally redesigning our academic programs, we were invited by Alan Tucker of SUNY Stony Brook to join a consortium he was organizing in response to the NSF Mathematical Sciences and their Applications Throughout the Curriculum initiative. The project, the Long Island Consortium for Interconnected Learning in the Quantitative Disciplines (LICIL), was intended to promote both a greater degree of realistic applications in mathematics offerings and a greater degree of mathematical sophistication in the offerings of the client disciplines ranging from the traditional areas in the physical sciences to the life sciences, the social sciences, business, technology, and even the humanities. The nine specific goals of LICIL were:

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- To increase connections between mathematics and other quantitative disciplines
- To change modes of instruction and learning
- To encourage the use of educational technology
- To encourage development of new interdisciplinary courses
- To encourage calculus reform activities
- To encourage precalculus reform activities
- To unify courses, such as statistics, that are taught in different departments
- To increase the number of students from under-represented groups entering quantitative fields
- To improve teacher training for K-12 education.

This project provided a framework under which we could completely revitalize and refocus Farmingdale State's quantitative programs, since virtually every one of these areas is something that is important to the institution's mission.

The primary tenet in the LICIL project is that mathematics is a central discipline that connects to most other academic areas. Our experiences have verified this. We began our revitalization activities a decade ago with changes that eventually involved the entire mathematics curriculum and then, in conjunction with faculty from most other quantitative disciplines, developed ways in which mathematics and quantitative literacy have been incorporated into courses in most other areas of the college's academic programs. We will describe many of these changes below. We will also discuss the impact on the students, the faculty, and the institution. Finally, we will discuss how our experiences at Farmingdale State can be used by other institutions to implement large-scale changes in quantitative literacy in their own curricula.

Changes in the Mathematics Curriculum

The revitalization of Farmingdale State's programs entailed the creation of an academic culture that fosters interdisciplinary cooperation and innovative instruction in all quantitative disciplines. In particular, these innovations include a restructuring of all mathematics courses to "reform curricula" in developmental mathematics, college algebra, precalculus, calculus, and post calculus courses, and involves all members of the mathematics department, including adjunct faculty. The overriding emphases in all our mathematics courses are to stress conceptual understanding and to apply the mathematics in realistic contexts via modeling. A special focus is use of real-world data, both as a source of mathematical problems and as a motivation for the mathematical developments. We have found that these philosophies have transformed the courses, and the entire mathematics program, into something that directly supports the mathematical needs of our other departments. In turn, it provides the other disciplines with the quantitative foundation on which to build the use of mathematics in their courses. This is quite unlike the traditional, skills-oriented mathematics courses we used to give that never seemed to connect to the other disciplines in students' minds. Specifically:

- Our developmental mathematics sequence is based on the text Mathematics In Action, that was developed by the NSF-supported collaboration *Consortium for Foundation Mathematics*. Arlene Kleinstein, one of our math faculty, is a member of that project team.
- Our precalculus offerings are based on Functioning in the *Real World: A Precalculus Experience*, which was developed by the NSF-supported Math Modeling/PreCalculus Reform project. Sheldon Gordon, who headed that project and is principal author of the text, has since joined Farmingdale State's faculty.
- Our calculus offerings are all based on texts that were developed by the NSF-supported Calculus Consortium based at Harvard, including *Calculus* both in our university calculus track and in our alternate track for non-majors, and *Multivariable Calculus* in our calculus III course.
- Our differential equations course now incorporates *Interactive Differential Equations* (workbook and CD-Rom) by West, Strogaty, et al, that complements the emphases on a qualitative approach to the subject and the modeling of real-world phenomena.
- Technology has been integrated into all math offerings. All students in developmental math, precalculus, calculus, and above are required to have and use graphing calculators. Students in multivariable calculus, differential equations and linear algebra utilize computer software packages such as Multigraph, Derive, Mathematica, MPP, and Matlab. Students in statistics are required to use a statistical calculator and the software package Minitab. Students in finite mathematics use spreadsheets and special software packages for matrix algebra and the Simplex Method.
- The math department has received several grants to examine the implications of hand-held computer algebra systems on the entire math curriculum from introductory algebra up through upper division offerings. The math faculty are working with faculty from all the other quantitative disciplines to develop a comprehensive strategy for either implementing the use of such technology or adjusting the content of all courses to reflect the ready availability of such technology even if it is not actually used by the students in particular courses.
- Writing and communication skills are another important dimension of many of these mathematics courses. Students are expected to conduct and write up individual and/or small group projects and to make presentations based on their projects, something which takes place in courses at all levels from precalculus and introductory statistics up through advanced offerings for the majors.

Another important dimension of revitalization in mathematics is our new B.S. program in Applied Mathematics. This program is designed for students with an interest in the mathematical sciences who may not have achieved their full potential in high school or who have never thought of mathematics as a potential career. We specifically recruit students in precalculus and first-year liberal arts math courses by giving them meaningful mathematical experiences that they can excel at and by demonstrating to them that the *practice* of mathematics is very different from the type of mathematical education most have previously received, which is typically designed to prepare students for subsequent courses. In particular, our goal is to build a new type of math major with highly portable skills (e.g., analytical thinking, problem solving, and communication ability) as well as contextual skills (e.g., computer programming), all based on a strong foundation in applying the mathematics to other disciplines. In the process, our emphasis provides the mathematical experience the other disciplines want, so that they can build upon it.

LICIL Curriculum Projects at Farmingdale State

On a larger scale, the entire institution has recognized the need for both a multidisciplinary approach to education and a greater level of emphasis on quantitative reasoning. This reflects a new focus on and sensitivity to the need for multidisciplinary education in today's workplace, particularly the high-tech workplace here on Long Island. Employees need quantitative skills, though not necessarily traditional algebra skills. They need to see the mathematical component in a situation (be it a set of data or a graph or a quantitative description of a process), to understand the mathematical ideas that arise and how those ideas naturally lead to mathematical problems that require solutions, be comfortable with a variety of mathematical tools (pencil-and-paper, calculators, software packages, etc) and, be able to communicate their findings to others. If they are to do this on the job, they need to develop these same skills in their coursework in all disciplines. Fortunately, our reform efforts in mathematics set the stage to carry over these same philosophies to the other disciplines.

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The LICIL project provided the framework for involving large numbers of faculty in the development and implementation of many curricula changes in this spirit. Much of this was accomplished through small summer grants, on the order of $700-$1000 per person, primarily to faculty working in interdisciplinary teams. The curriculum projects that were developed range across activities involving many disciplines we originally never envisioned as being part of the project. What is especially significant is that the spirit of these curriculum reform activities have far outlived the duration of the LICIL project. Over the years, our projects have included:

- In one of our statistics classes, the students work jointly with students in a manufacturing engineering class. Teams of manufacturing engineering students design and manufacture a machine tool to produce models of airplanes. The statistics students come into the lab to perform an analysis to see which tool best meets the design specification, thus emulating a real world manufacturing environment.
- We developed several student workshops such as the *Interdisciplinary Workshop in Mathematics, Physics, and Technology*, which is designed to facilitate the transfer of concepts from the mathematics classroom to the physics classroom. This is but one of a variety of collaborative efforts involving faculty from several departments who are working in concert to achieve common educational goals.
- In another student workshop, students taking Ordinary Differential Equations (ODE) visit a physics laboratory to conduct a variety of physical experiments to obtain empirical data with which to verify the analytical results obtained in the ODE classroom.

- Our Urban Sociology course now includes a sequence of quantitative modules created with LICIL funding so that the students work with real world census data taken from a CD-Rom and the World Wide Web. The goals of these modules include increasing the students' ability and comfort level with quantitative work, the integration of critical thinking, and the reinforcement of clear communication skills and teamwork.

- The Department of Construction/Architectural Engineering Technology has restructured several of its courses to directly link with mathematics and physics. An environment is being created that fosters peer tutoring and support groups, active and cooperative learning, critical thinking, and student self-assessment. In addition, the department incorporates capstone student projects and makes extensive use of the World Wide Web for instructional purposes.

- Faculty from mathematics and physics have developed a joint course in Fourier series, Fourier transforms, and vector calculus.

- One of our math faculty has developed an interdisciplinary course in mathematical modeling in the biological sciences in conjunction with faculty from biology and biomedical technology. The course features a variety of student project activities in which applied math majors are teamed with students from biology and from biomedical technology so that the math students can bring their more sophisticated mathematical knowledge to bear while the other students will bring their more detailed knowledge of the biological processes and systems.

- As a direct consequence of the math department's adoption of graphing calculators in its courses, the chemistry department redesigned its laboratories around the same calculator and the use of the CBL for data acquisition. For instance, in the titration experiment, the students collect data, plot it on the calculator and locate the point of inflection of the titration curve, thus showing a nice connection between chemistry and mathematics. Since making these innovations, there has been significant improvement in the students' laboratory results, a clear decrease in math anxiety, and an increasing awareness of the role of mathematics in chemistry.

- The biology department has incorporated two lab modules into anatomy and physiology that introduce the students to the statistical analysis of experimental data. The department also uses a computer based data acquisition system that allows students to record and store measurements in the laboratory. Using this software, teams of students analyze results from graphical representations of the data, something that is a major focus in many of the mathematics courses.

- We created a new course on mathematical methods in linguistics, which is designed primarily for liberal arts and computer science students. Using basic algebra and statistics, the students investigate areas such as the rank and frequencies of words in languages and how the core vocabulary is retained or lost in a language. Cluster analysis is used to study the closeness of languages in the same family. The mathematical techniques needed are taught before the corresponding linguistics application is studied.

- A group of faculty from electrical technology and mathematics collaborated to develop a pair of modules to link several courses in electrical technology to precalculus through the study of sinusoidal functions that are used to model audio amplifiers. In the process, the faculty discovered some subtle, yet important, differences in how the word AfrequencyA is used in the two fields. Clarifying this discrepancy for students should contribute greatly to easing their transition between the two courses.

- An interdisciplinary workshop was created for students in Precalculus and Electric Circuits I. The students work on a series of technical problems involving basic mathematics skills. The graphing calculator is used in this optional workshop.

Although many of the activities started under LICIL are still in effect, by far the most significant legacy of the project are the fundamental changes in approach and attitudes toward teaching. The exact activities change over time (they come and go depending on who is teaching which course and other factors); but the attitudes of the faculty and the administration and the new student-centered and multidisciplinary-centered attitudes toward teaching have changed fundamentally. Philosophically and intellectually, the faculty is now prepared to undertake interdisciplinary work, something that would have seemed awkward and would not likely have been well received a few years ago. For instance, prior to the project, there were no interdisciplinary courses or programs; now they are fully accepted as part of the standard offerings at the college. Thus, it is not just the students, but also faculty and administrators who are the beneficiaries of our efforts at quantitative literacy and interconnected learning across the disciplines.

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Connections With Business, Industry and Government

Farmingdale State has also made substantial progress in creating connections with business, industry, and government. At a regional conference hosted by the college and attended by 41 local companies, one representative from local industry stated "*... the large size companies that can afford hiring specialized engineers and technologists have almost disappeared from Long Island... the remaining small size companies can only afford hiring a limited number of professionals who possess a wide knowledge base*" and another stated *"... once a task is completed and the engineer is unable to work efficiently in a different area, his/her service will be terminated."* These remarks, together with subsequent surveys, indicate that to maintain our students' long-term employability, broad multi-disciplinary programs that emphasize flexibility in thinking are essential to prepare the future workforce. A fundamental component of such training must be quantitative reasoning.

The mathematics department's *Center for Applied Mathematics* is also very active in the *Route 110 Redevelopment Corporation*, a non-profit organization dedicated to enhancing the development of the Route 110 corridor in multifaceted ways. Our involvement enables us to learn about the needs of local industry through networking activities and also provides us with a source of real world student projects.

Farmingdale State has also developed a collaborative relationship with the Cold Spring Harbor Laboratory in the areas of bioscience, bio-informatics, and automation technology. New York State committed over $25 million of state funds to the development of a 100,000 square foot bioscience research facility at the college to be run jointly by Farmingdale State and Cold Spring Harbor Laboratory. This venture has been so successful that a second building is now being added to the on-campus complex. As part of the agreement, our students will be able to use laboratory space. The joint relationship brings start-up companies spun out of Cold Spring Harbor research projects to the campus and provides the opportunity to develop curricula tailor-made to the needs of these new bioscience firms. This also provides opportunities for student internships, senior level projects, and faculty consultations. Our new course in *Mathematical Modeling for the Biological Sciences* is intended as the math department's first step in this direction.

The geographical region surrounding the campus is undergoing a transformation from a commercial shopping area to one that is a major center of biotechnology research and development, and the college is central to this development. The types of industry that will be attracted to the new Route 110 corridor will increasingly need employees at all levels who have a significant degree of quantitative skills. It will be the responsibility of the college to produce and maintain this workforce and this is not something that can be achieved exclusively through mathematics courses. Rather, it requires our maintaining and expanding a broad program in developing quantitative literacy for all students in all academic areas.

New Directions

One of the strong messages that has come from our relationship with the Route 110 Redevelopment Project is the essential need for students going into the biosciences to have a stronger quantitative background, one that is different from the traditional mathematical program that was originally created to support the physical sciences. In response to this challenge, we have begun (with support from the NSF) to develop a new curriculum geared to the mathematical needs of the biosciences. Virtually all of the existing models for mathematics and biology start at either the calculus or the differential equations level. However, here at Farmingdale State (and likely at most other institutions), students going into biology typically start their program at the precalculus (if not the college algebra) level.

Our first step in creating a mathematics curriculum to serve the biosciences is to develop an alternative to our regular modeling-oriented precalculus course. The focus here will be almost exclusively on mathematical models that arise in the life sciences. In addition, we are working with our biology faculty to develop an accompanying one-credit lab course that will be taught in the biology department. In this lab, students will conduct a weekly experiment in which they will collect a set of data and analyze it using the mathematical topic (typically having to do with one of the families of functions that are the focus of the math course). In this way, the students will gain a much deeper appreciation of the value of the mathematics they are learning by actually using it. In turn, the quantitative ideas and methods will be something that can easily be built upon in subsequent lab courses in the biosciences, so that the quantitative level of all courses given by biology will be able to increase significantly.

Simultaneously, we have begun looking for ways in which we can extend these ideas to subsequent mathematics offerings to make the biosciences a significant aspect of our entire program. We have already begun rethinking both our ordinary and partial differential equations courses to reflect this, as well as the senior projects course. The next step will be to create a more appropriate calculus-level course for the bioscience students, one that will likely also include a joint lab component to be run by the biology department.

Interestingly, once the news about this project has gotten out across the campus, the math department has been approached by several other departments about the possibility of developing comparable collaborations with a math course and an associated discipline lab. For instance, the technology department wants to use this as a model for a new statistics offering in Statistical Process Control where we would teach the course and they would offer an associated lab course in which the technology students would conduct experiments tied directly to the statistics topic of the week.

Another important theme evolving at Farmingdale State is that no science, mathematics, engineering technology (STEM) course should stand alone—all STEM courses should have links in subject matter, active learning, contextual learning and realistic applications. In order to develop this theme, our vision includes the establishment of a program in which every STEM student will be provided with an applied learning experience in conjunction with corporations and government agencies that submit research projects to be investigated by teams of students under faculty supervision. We foresee that many of these projects will produce "spin-off" mini-projects that will be appropriate for introductory courses, thus introducing beginning students to real world industrial applications early on in their education. This would address the need expressed by most of our students to see how their classroom work is relevant to the real world. We have already involved students from our introductory statistics course in performing analyses of traffic studies of the Route 110 corridor conducted on behalf of several local and regional governmental agencies.

Impact on Students

All students majoring in the quantitative disciplines at Farmingdale State have experienced the effects of the methods described above and many "non-quantitative" majors have experienced these approaches while meeting their general education mathematics requirement. For instance, many introductory statistics students work on real world projects using Minitab or another statistical package. Example projects include a traffic flow survey conducted for the Route 110 Redevelopment Corporation, an analysis for a major car rental company, and an analysis of the utilization of ATMs for a local financial institution. Also, it is a college requirement that all students in our baccalaureate programs engage in a substantial real world learning experience such as a project suggested by local industry, a civic association, or a faculty member. In Applied Mathematics, this requirement is met through the required senior Applied Mathematics Seminar Course.

At the end of every semester, we have presentations of student projects. Many of the presentations are of professional quality. In fact, some of our students from courses as "low" as college algebra, precalculus, and introductory statistics have presented their work at local, at state-wide, and even at national conferences and have matured tremendously in the process. In one case, a student presenting his work at a local LICIL conference on a project in his precalculus class was actively recruited by a physics professor at Stony Brook to apply to their graduate physics program. We have seen students start as weak students at Farmingdale State and end up as successful students in graduate programs at major universities. In site visit reports and in reports from the LICIL external evaluator, reviewers noted our ability to successfully work with students encompassing a wide range of preparation.

Four of our former Farmingdale Applied Mathematics students, who went on to earn graduate degrees at a major university, are currently working as adjunct faculty members in our department. When asked about his education in an interview, one of these students stated "Every field of applied science and technology needs a basic tool to operate and that tool is mathematics. An Applied Math major is exposed to the sciences, computer technology, business and industry in his or her studies. The Applied Math major has the flexibility to enter almost any field and apply the knowledge gained in his or her studies in the real world. That flexibility is a very valuable tool." This quote exemplifies some of the values instilled in our students through our departmental philosophy and approach. Other Applied Mathematics students are now successfully working in teaching, computer science, business, and finance as well as attending graduate school. We believe that this is an indication that our pedagogical methods are working.

Faculty from the other quantitative disciplines at Farmingdale State also appear to be happier with the students who come through our courses than in the past. Certainly, there are still complaints that students are not as good as they were years ago. But there also seems to be a general perception that the students are learning more mathematics that is useful for courses in the partner disciplines.

At the same time, the majority of the students seem very appreciative of the changes that we have made. We no longer hear the old complaints about "why are we learning this" or "when will we ever use this"; the students see the immediate applications of the mathematics in contexts that are real and interesting to them. In turn, as mentioned previously, we now recruit our Applied Math majors in courses such as precalculus; if these courses didn't capture the imaginations of the students, there is no way that they would be willing to switch their majors.

Lessons to be Learned

Colleagues who have visited Farmingdale State as external evaluators for departmental reviews or grant on-site visits have very graciously made quite complimentary comments regarding our accomplishments. In reflecting on this, we would like to share some of our thoughts regarding our progress including some lessons we have learned:

- The change in institutional designation from a two year school to a four year school with a very specific mission to serve the changing regional economy with a high technological focus forced us to rethink all of our programs. Moreover, the fact that the new institutional focus was on technology made quantitative literacy an essential dimension for all students.
- An institutional program such as LICIL can result in a new spirit of interdisciplinary cooperation and instructional reform that prevails over a long period of time. But it does require a strong institutional commitment, both financially and academically.
- It helps if the project leaders have many professional connections on and off campus and have a good working relationship with the campus administration.
- The mini-grants provided under the LICIL grant were enormously effective, both at Farmingdale State and at the other LICIL institutions, in encouraging large numbers of faculty to become involved in curriculum renewal efforts. It was certainly not the money ($700-$1000 per person) that was the impetus to get so many people to work on these projects; rather the mini-grants provided the opportunity and encouragement that recognized and gave visibility to people's activities.
- We have always been very fortunate at Farmingdale State that through several administrations, the college's administrators—the president, the provost, and the deans—went well beyond being supportive of our projects, but strongly encouraged faculty to become deeply involved. The administration here dramatically recognized project-related activities by awarding merit salary increases to faculty who were especially active in the project and counted such involvement heavily in tenure and promotion decisions. This strong administrative support continues, as the college moves to implement its new mission of serving not just its students, but also the needs of business and industry in the region.
- Many of the Farmingdale State administrators have themselves come from academic positions in the sciences and other technological areas, and so have a thorough understanding of the

importance of mathematics as the central link in all quantitative disciplines.

- The State University of New York and the faculty union, United University Professions, have a faculty grant program that is administered independently at each SUNY campus. At Farmingdale State, almost all of the faculty who received awards from LICIL also received funding under this program to provide either matching funds for released time or further funding for released time to assist them in implementing their project development work.
- Project leaders should help coordinate project activities and act as cheerleaders for the collective undertaking, not run such a project. Good ideas can come equally from all participants and are far more likely to be implemented if they come from the grass-roots level. In this regard, faculty should feel free to participate in the project on their own terms.
- It is essential to respect competing alternative approaches to instruction rather than to attempt to inflict a single approach on all.
- It is important to learn what your colleagues are already doing, especially in the other disciplines and see how it can be incorporated into the project's agenda.
- Faculty should come to view new instructional approaches as a natural intellectual process similar to the questions and new approaches that go on in research.
- Curriculum renewal should be viewed as an ongoing process, not as something that is established once and then allowed to exist indefinitely. Changes are taking place too rapidly in every discipline today and, as the need for collaboration grows, the need to rethink and redevelop the corresponding curricula becomes ever more compelling.
- When individual faculty members come together, they have a more visible, persuasive impact on administrators, on other faculty, and on each other. This dynamic provides the force needed for a large scale project to succeed.
- The LICIL project at Farmingdale State developed a structure with ongoing meetings, roughly twice a semester, involving all faculty involved in project activities. This motivated the faculty involved to maintain a high level of project activity. At the same time, the frequent meetings contribute to a high level of enthusiasm among the individuals involved, which tends to infect other faculty and draw them into the project.
- The frequent project meetings are part of an institutional culture that encourages numerous meetings at the departmental, college, and institution-wide level. In turn, this leads to a high degree of interdisciplinary contact, which makes it easier to build the interdisciplinary activities.
- The college and the faculty take the challenge to provide the students with the best possible education very seriously. In turn, this means that the faculty are very willing to put their students first, even if it means working harder to improve student education.

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