Bridging mathematics and the sciences via the environment[1]

Stephanie Fitchett[2]
Honors College
Florida Atlantic University

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Abstract

At Florida Atlantic University's Honors College, faculty are working together to build an interdisciplinary curriculum for lower-division mathematics, biology, chemistry and environmental science. Traditional calculus and statistics courses include examples that show how mathematics is used to understand questions about the environment. Materials are adapted from outside sources or developed through collaboration between mathematicians and scientists in the college. Many of these materials are small projects, designed for students to explore collaboratively, with the assistance of a graphing calculator, computer algebra system, or statistical software. Complementing the mathematics program, lower-division science courses bring science and mathematics out of the classroom and into the community, using local ponds, lakes, forests and greenways as science laboratories. Student and faculty teams collect data on the water quality in area ponds, the diversity of wildlife in more than 250 acres of nearby preserves, and the impact of a growing population on the environment. They then bring their studies back to the classroom and use mathematics and statistics to analyze and model their data. A series of three new "links" – one-credit courses that are team-taught by scientists and mathematicians – focus on the analysis of student-collected data using increasingly sophisticated tools.

The project is supported by a National Science Foundation grant. The project goals are for students to understand the interdependence of mathematics and the natural sciences, and to be able to apply what they learn in the classroom to hands-on scientific studies. For both faculty and students, the project aims to integrate teaching, learning and research in a holistic form of scholarship.

[1]This project was also the subject of a talk at the 2nd International Conference on the Teaching of Mathematics in Hersonissos, Greece, July 2002, and a condensed form of this paper appears in the Conference Proceedings.

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1 Introduction

In the last century, the undergraduate curriculum in the United States has experienced tremendous growth in specialization of programs and courses, and while this specialization has allowed great advances in many fields, it has also, unfortunately, led to a great deal of fragmentation in the learning experience of students [GR]. Like faculty at many other institutions across the country, the mathematicians and scientists at Florida Atlantic University's Honors College are making a concerted effort to generalize and integrate the undergraduate curriculum, and in the process build a sense of community among both students and faculty on the campus. The project described here focuses on using environmental issues to bridge mathematics and the natural sciences. The environment was specifically chosen as the integrating theme because problems relating to the environment often involve many disciplines, including biology, chemistry, geography, law and public policy, economics, statistics, and mathematical modeling.

The National Research Council Committee on Undergraduate Science Education calls for the primary goal of institutional efforts to reform science, mathematics, engineering and technology undergraduate education to be the following [NRC]:

> Institutions of higher education should provide diverse opportunities for *all* undergraduates to study science, mathematics, engineering, and technology as practiced by scientists and engineers, and as early in their academic careers as possible. [Emphasis in the original.]

In the preface to her book, *Rosalind Franklin and DNA*, the historian Anne Sayre [S] notes that, as educators, we are skilled at communicating the content of science but not the process. Even traditional hands-on laboratories, while extremely valuable in developing observational skills and manual dexterity and in providing a useful connection between theory and practice, rarely generate the kind of enthusiasm that we might anticipate.

In order to study science and mathematics as practiced by professionals, and to study the process as well as the content, students must learn to integrate, rather than compartmentalize knowledge, and they must be engaged in real scientific studies. To these ends, the Honors College program has students

- engage in science and mathematics as active investigators rather than as mere spectators or passive consumers of information;
- experience the sciences and mathematics as interconnected and mutually informing areas of human knowledge rather than as isolated fields separated by impervious disciplinary boundaries; and, finally,
- build an understanding of the connection between science and the world beyond the classroom, especially by exploring local and regional environments.

Our goal is to give students hands-on field and laboratory experience in collecting and interpreting data, and, at the same time, to present them with a valuable opportunity to contribute to an ongoing scientific investigation of their own environment.

The desirability of these experiential, connection-building learning activities is well documented, and many successful reforms have been implemented at schools across the United States. Relevant mathematical activities range from the adoption of reform calculus texts and courses ([SM], [HHG], [CH], for instance), which make natural and social science applications central to the courses and/or involve students directly in exploring and explaining physical phenomena; to the development of integrated courses in mathematics and science, generally offered as an alternative to the traditional sequence of courses ([Ca], [Han], [DAC], for example); to the offering of programs, such as that at Evergreen State College, where the traditional role of a course has been replaced by wholly integrated semesters of study.

While some faculty members at the Honors College would like to emulate some of the more radical, and highly successful, programs, such as that at Evergreen State, the credit hour structure, graduation requirements and general limitations imposed by a statewide university system will prevent the adoption of such revolutionary approaches to interdisciplinarity. Other faculty members would like to develop an integrated mathematics, chemistry and biology course, somewhat like the Drury experiment, but programmatic obstacles would prevent requiring such a course for all students, and we lack both the student body and the faculty resources to offer an alternative track to traditional calculus or science sequences. We strive, for the moment, toward smaller successes within a fairly traditionally structured program: an integrated lower division mathematics and science curriculum, valuable for *all* students, but particularly well-suited for majors in the natural sciences and related disciplines. The project components fall into four broad categories: science, mathematics, linked courses, and community involvement. Each is described further in the sections that follow, but the majority of the discussion is devoted to the projects adapted, adopted or developed for the introductory mathematics and statistics courses.

2 The College and its Setting

The Honors College at Florida Atlantic University opened in the fall of 1999 as an autonomous, residential, liberal arts college within the larger Florida Atlantic University system. As of Fall 2002, the college enrolled approximately 270 students. At full capacity (Fall 2005), the Honors College will enroll approximately 500 students and employ close to 50 faculty members, numbers that strongly promote close faculty-student interaction and discovery-based approaches to learning. Present enrollment trends suggest that a significant fraction of our students (roughly 40%) plan to concentrate in areas of the natural sciences that include pre-medicine, biology, and marine and environmental studies.

The Honors College is located in Abacoa, a 2055 acre, master-planned, mixed-use community, that is currently under development. The planning of Abacoa has been guided by the philosophy of the "new urbanism," which seeks through architectural strategies to facilitate a sense of community among residents and to provide a connection to the natural environment via provision of greenways and lakes. To this end, some 259 acres of preserves have been retained, along with observation points, walking trails, and protected native habitats. A significant area of the development consists of varied aquatic systems, including lakes, ponds, and connecting streams, providing the opportunity for faculty to bring science and mathematics out of the classroom and into the surrounding community.

3 Courses and Activities

3.1 Introductory Chemistry and Biology

All Honors College students are required to write a senior thesis, so, in addition to the general goals described above, this project is intended to acquaint students with the research process early on, preferably in the first year. For the science component of the project, students in first and second-year chemistry courses, as well as most second year biology courses, are required to design and complete semester-long research projects, and present their results (usually both orally and in a formal report) at the end of the semester. The greenways and waterways of the community are used as a living laboratory for many of these early research projects, which are suggested and supervised by faculty, some of whom have their own research projects going in the same areas.

For example, one student project examined the relationship between pH and the Dissolved Oxygen concentration in Abacoa waterways over a several week period. Next year, a suggested project will be to examine this relationship over a 24 hour period in two different sorts of water bodies (golf course lake, productive aerated lake, canal, etc.). Presumably, these can be roughly modeled individually by sinusoidal functions, and a system of differential equations or difference equations could describe the changing relationship between the two that is due to the process of photosynthesis ($C_2 + H_2 0 \to CH_2O + O_2$) and its reverse, respiration.

As in this case, it often happens that one research project will suggest another, and by having an interdisciplinary group of faculty discuss the projects from all different disciplines, we find new ways to make connections between the disciplines, expand our library of class examples, and come up with new project ideas.

The following discussion of mathematics and statistics courses will provide an indication of some of the biology projects our students and faculty members are working on.

3.2 Introductory Mathematics and Statistics

One goal of this project is the creation of stronger connections among the introductory science and mathematics courses. To this end, we are working to weave an environmental thread into the introductory mathematics and statistics courses. Some of these materials are small examples or exercises used in classroom discussions, but many are larger projects in which small groups of students explore, analyze and model environmental data.

We have adapted project materials from several sources. Generally, we give written assignments to groups of 2 to 4 students, and expect them to solve an involved problem or series of problems — in most cases using graphing calculators, a spreadsheet, or a computer algebra system — then provide a written report of their findings. Depending on the course, the instructor, and the depth of the individual projects, students in statistics, precalculus, or calculus may complete anywhere between two and eight such projects over the course of the semester. Resources for projects abound. Duke University's Connected Curriculum Project modules [MSm], COMAP's Interdisciplinary Lively Application Projects [P], and Mooney and Swift's text [MSw] are some of our favorites.

Statistics. For statistics, educators are nearly unanimous in their encouragement for students to work with real data, and preferably student-gathered data [Ho], [CHRT], [M], [Cob], [WS]. As long-term research projects are incorporated in the science program, we are naturally developing a large bank of environmental data that can be used as examples and projects in the introductory statistics course. So far, students in statistics have worked on a series of five short projects analyzing data on levels of pollution in Lake Erie (materials adapted from [USMA]), as well as aggressive behavior in the Giant Damselfish (*Microspathodon dorsalis*) and characteristics of Abacoa's gopher tortoise population, both based on data collected by Honors College biology professor Jon Moore.

Precalculus. In precalculus, one of our projects is based on a local gopher tortoise population. I am not expert enough with images, latex and pdf converters to provide a picture of a gopher tortoise in this file, but if you are curious, you can find pictures on our project website [FAU]. In any case, there are about a hundred gopher tortoises that live on a gopher tortoise preserve in the greenways of Abacoa. In fact, before building could begin in the Abacoa development, because the land was home to a population of this threatened species, the developers had to move all the gopher tortoises to a protected location, namely a preserve located about a half mile from our campus.

In the last two years, biology professor Jon Moore has spent over 250 hours chasing, catching, marking, measuring and observing gopher tortoises. Because of the threatened status of the turtles, state and federal wildlife officials are especially interested in what Jon learns about their habits and habitat. The biggest threat to the turtles is the destruction of their habitat as development encroaches further and further into their natural territories.

Jon collects size, weight, sex, age, and infection data on the tortoises, as well as information on the use and location of their burrows. His biology students are studying the effects of greenways management, specifically mowing and burning practices, on the gopher tortoises [K].

For precalculus, we have borrowed Jon's gopher tortoise data and turned it into a curve fitting project. Students look at the relationships between the length of the top shell and the length of the bottom shell, length of the top shell and width of the top shell (both highly correlated, linear), the length of the top shell and the shell height (still linear, but with lower correlation), weight as a function of age (a power model), and top shell length as a function of age (a logistic model).

Calculus. At the calculus level, our efforts are supported by the Harvard Consortium text [HHG], which is particularly strong in its inclusion of examples from the biological sciences. For projects, we have used modules on logistic growth, air pollution, and the SIR model from Duke University's Connected Curriculum Project [MSm], which contains a collection of web-based environmental science modules as well as some longer projects. We have also used materials from Project Intermath's collection of modeling problems [P], including, *Rising Mercury in Water*, in which students use difference equations to investigate the bioaccumulation of mercury in humans, and *Lake Pollution*, in which students investigate levels of pollution in a river and lake system. For more hands-on experiences, we have had calculus students use probes for Texas Instruments calculators to measure salinity in a system of connected water tanks, then model the data using exponential functions and develop a differential equation model from their data. We discuss how the system could be used to model pollutants in a system similar to the one they encountered in the Lake Pollution project, and how, in practice, measurements might be made over a period of months or years, rather than minutes.

3.3 Linked Courses

To help students make connections between their science experiences and mathematics, we are developing new "linked" courses. The original curriculum design for the college, and the graduation requirements for students, include one-credit, team-taught, interdisciplinary courses, and we have taken advantage of this curriculum structure to offer courses on mathematical modeling for the environment, data analysis, geographic information systems, and a senior seminar. Typically, "links" are one-credit offerings, co-taught by instructors in different disciplines, in which students discuss common themes, examine disciplinary assumptions, and explore areas of conflict in a topic which crosses disciplinary boundaries.

Data Analysis. The Data Analysis link provides students with the opportunity to statistically analyze the data they have gathered for their science projects. The course is available to students who have had one semester of statistics and are currently enrolled in a first or second year science course that includes a project component. Through the discussion and critique of a variety of projects in different disciplines, the students evaluate choices made in the design of studies and in the collection of data. To analyze their data, students are expected to make appropriate choices in the application of statistical methods.

For example, the first Data Analysis class worked with a data set of approximately 1000 sea turtle nests on an 11-mile stretch of beach directly east of the college. Biology professor Jim Wetterer and some of his students, together with volunteers from a local sea-turtle monitoring organization, collected data on the species of sea turtle, the locations of the nests, types and number of ants found on the nests, number of eggs in the nest, and number of live hatchlings, among other variables. Students are analyzing the data, using techniques learned in the introductory course, to answer questions about, for instance, the relationship between the number of ants found on a nest and the nest's location (distance from vegetation or high tide mark), the relationship between the number of eggs laid and the species of the turtle, or the relationship between ants and live hatchlings. The students discussed multi-linear regression, which was a technique that is new to them, then used the techniques they had learned to build a model that predicts the percentage of live hatchlings from a nest, based on the variables they determine are important to the model. Later in the semester, students analyzed data from their own projects, or from a project of a faculty member in their chosen discipline, on an individual basis. Near the end of the course, they presented their analysis to the class for discussion and refinement, then wrote a final paper discussing their findings.

Environmental Science Seminar. The Environmental Science Seminar is designed to introduce students to multidisciplinary collaboration and peer-review, two important aspects of science that are often overlooked at the undergraduate level. The seminar also helps prepare students for the writing of their senior theses by involving students in the design and critique of their own projects. Junior year participants do directed reading, and develop and present ideas for projects (working towards finding a project for their senior thesis), while senior year participants present results from their ongoing research projects. The seminar is attended by faculty members and students in chemistry, biology, mathematics, physics, economics and psychology.

Mathematical Modeling. The modeling link, being offered for the first time in the Fall of 2002, focuses on the process of building mathematical models, using spreadsheets and modeling software such as STELLA. Examples of environmental modeling materials abound, including the rich introductory texts of Harte [Har], Mooney and Swift [MSw], and Hadlock [Had], all of which are largely accessible to students with a background in calculus, which is a prerequisite for the Modeling link. In any one semester modeling link, students are introduced to several types of modeling, including some or all of steady state box models, non-steady state box models, chemical equilibrium models, and population models.

We plan to eventually move this course toward individual modeling projects. In the future, for a student to enroll in this course, it may be necessary to have on hand a data set which lends itself to a modeling approach. For example, a student who wishes to explore the fluxes of phosphorus from lake sediments into the water column or do more sophisticated diffusion modeling using Fick's first and second laws, will need to bring to the course a coherent set of measurements of dissolved phosphorus in sediment pore waters, determined at appropriate cm-scale intervals [B].

Geographical Information Systems (GIS). Also being offered for the first time in the Fall 2002, the Geographical Information Systems (GIS) link is primarily for students in their junior year, and is intended to bridge the natural and social sciences. GIS technology is an increasingly useful and popular way of recognizing and studying relationships in our environment by analyzing spatial patterns. This is becoming a standard research tool among environmental professionals and in graduate institutions. The increased demand for its use has led to the incorporation of GIS-based curricula into undergraduate education.

Using GIS, students examine a number of environmental issues. For example, they may examine the spatial arrangement of Gopher tortoise burrows and grazing areas and determine how this arrangement relates to topography and vegetation. As in the case of other wildlife, the increased human population and traffic may directly or indirectly impact not only the population of tortoises, but also where they burrow and graze. Time series spatial data will allow students to use GIS to examine these and other related questions. In addition, data collected for chemistry projects on fertilizer application may be used to study the leaching of nitrogen and phosphates and eutrophication of local water bodies. GIS will allow the students to incorporate distance from fertilizer application and topographical variables to the chemical study of the water bodies.

4 Community Involvement

The developing nature of our surrounding community allows for interaction between the university and the residents, and we have made a concerted effort to involve environmental professionals from the community in our academic activities. For instance, in the summer of 2001, we hosted a conference attended by representatives from about 30 local environmental organizations at which we shared the curricular goals of our program and they shared their research interests, often suggesting opportunities for students to intern within their organizations or providing ideas for faculty-supervised student projects.

Several students have completed internships related to the environment, many contacts for which were initiated at the community conference, and more are in the works. The intern activities have ranged from biological field work to research on state environmental organizations, and from summer camp education to database design and building.

Finally, we are in the process of surveying residents of the surrounding community to determine their environmental concerns and their level of interest in participating in university forums on the use and management of the community greenway systems. We hope that a few will be interested enough in the science of the greenways to attend a spring conference at which students will present some of the research done in Abacoa.

5 Assessment

At the time of this writing, the data available are student survey responses from the beginning and end of project-related courses in the 2001-2002 academic year. The surveys asked students to respond to statements about their academic interests, their beliefs about the degree of connectedness between math and the sciences, their understanding of inquiry-based learning, their ability to cite examples of the use of mathematics and statistics in science, their facility with writing and library research on scientific issues, and so on. Analysis of pre- and post-responses to the mathematics and statistics questions (for all students in one of the project courses, not just for students enrolled in mathematics or statistics) gives some evidence that the courses are making progress toward meeting the project's curricular goals. For instance, in response to the statement "I have a clear idea of the role that mathematics plays in scientific research," students responded on a scale of 1 (strongly agree) to 5 (strongly disagree). The mean difference in responses from the beginning and the end of the semester was significant at the 10% level (p=0.075), and two of the three other statements specifically geared towards mathematics and statistics generated similar differences in responses. (The third statement, which specifically asked about hypothesis testing, was not significant (p=0.29). This result is not surprising since the portion of students who had completed a statistics course was fairly small.)

Our sample was relatively small, and many students had completed only one or two courses of our 4-course requirement (2 mathematics, 2 natural sciences, including one with an environmental emphasis), so we by no means see the data as conclusive, but we are encouraged that our courses seem to be contributing to students' increased belief in the interdependency of mathematics and the sciences. Specifically, the data seem to suggest that mathematics and statistics courses, especially in conjunction with science courses, tend to help students see the dependency of science on mathematics, while science courses tend to help students recognize the interdependence of scientific disciplines. By the end of the 2002-2003 academic year, when more students will have completed the 4-course mathematics and science requirement, we hope to see more conclusive data.

A comprehensive project assessment is scheduled for the summer of 2003. It will include not only student survey responses, but review of student project reports by outside evaluators, as well as examination of the extent to which the project is contributing to the mission of the college.

6 Challenges and Rewards

To be blunt, the research projects in the sciences can be exasperating for instructors. Students sometimes want to adopt a 'save the world' mentality, and look for reasons to condemn the establishment. This may lead to research projects that are founded on rumors, not science, and the students may lack the science background necessary to truly understand analyze problems. While students are expected to work with, or at least get approval from, faculty on their project topics, our students are incredibly independent. Steering students toward interesting and accessible projects is sometimes challenging.

In some instances, even when the instructor thinks a project is on track, sometimes students do not make the connections that we would expect. For example, one chemistry project examined copper concentrations in soil and plants at different locations in Abacoa — in a golf course, in a canal, and in a greenway preserve. The students collected samples, dried them, added acid and dried again to remove remaining organics, diluted with water, filtered, then diluted again. They did solid lab work and explained their process carefully and concisely. But, in the end, they reported copper concentrations in milligrams per liter instead of parts per million. That is, they did not relate their findings (mass of copper in the sample) back to the mass of the original sample! This was one example of a project that had the potential to be outstanding, but turned out to be far less meaningful because, despite a lot of good work, the students missed something important about the point of the project.

Math and stats projects have sometimes been a bit more successful, partly because they are more carefully guided, with the whole class working on the same projects that the instructor had designed and worked out ahead of time. Perhaps our biggest challenge in mathematics and statistics courses is getting the students involved in hands-on data collection. Unlike most science courses, which include a three-hour weekly lab in addition to three hours of lecture, mathematics and statistics courses generally meet only four hours per week in three periods. The short class periods make field work difficult, and the lack of laboratory space makes it hard to gather data in the lab. Thus, we have been unable to employ as many hand-on activities as we would like. That is not to say that the students do not get opportunities for discovery in many of the projects, but the discovery is guided and structured, usually with data provided instead of generated of gathered. We have had some luck in sending students to the field to collect data if the process is carefully discussed in class, and students are provided with many deadlines, but response to these activities has been mixed.

In all areas, writing project reports has posed challenges. Students that complete projects must turn in written reports on their process and results, and while we knew this would be something new for many first-year students, and thus provided some guidelines, we are finding that we need to provide more support and examples in this arena. We are currently putting together materials to help students in writing reports, giving oral presentations, and preparing posters, with the expectation that a good project will lead to a strong report and presentation, something that has not always happened in the past.

On the rewards side, absolutely the best part of the project for faculty members has been the opportunity to interact professionally with colleagues outside of our own disciplines. We are becoming students of the interdisciplinary field of environmental science. And, despite the serious challenges to introducing discovery-based learning in lower division courses discussed above, we have been happy with what our students are learning. Even when a science project does not turned out as planned, the students are gaining a much better idea of what it means to *do* science than would be possible in a traditional lecture and scripted lab setting. Finally, we are very excited about the ties we are building between university and community.

7 Future Plans

Over the next year or so, we plan to continue the development of project ideas for mathematics and statistics, harvesting ideas and data sets from the science projects of our faculty and students. We hope to continue our long-term monitoring efforts (gopher tortoises, water quality), and use the resulting data and research to develop more connections between our traditional disciplinary courses.

We would be very interested in collaborating with and/or exchanging materials with interested parties, and we would be especially interested in adapting or helping to design additional materials relevant to the Florida environment — the Kissimmee River and Everglades restorations, beach preservation, or land use management, for example.

8 Conclusion

As a residential liberal arts college, the Honors College of Florida Atlantic University strives to provide students with a broad education, to demand critical thinking, to promote inquiry across disciplinary boundaries and to engender the desire for life-long learning. Our project has potential to make outstanding contributions to the mission of the college, by engaging students in discovery-based, interdisciplinary projects, and by providing faculty role models who, on a daily basis, exhibit the process of inquiry-based discovery, of continuing education, and of building and maintaining cross-disciplinary collaborations. Moreover, we believe the use of data gathered in (often collaborative) student and faculty projects, creates a sense of student ownership of the curriculum, and helps build a sense of community among students and faculty in mathematics and the sciences.

As is generally the case with any substantial change in the curriculum, the success or failure of the change depends largely on the faculty involved: the support, enthusiasm, time and effort they are willing to provide for the project. A National Science Foundation grant supports the initial faculty efforts, but this project is seen as the building of the college's science and mathematics program for years to come. Thus far, college support has been strong and as generous as the budget situation will allow.

More about the project, including links to some materials we are using, is available at the project website [FAU].

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