USING ENVIRONMENTAL SCIENCE TO BRIDGE MATHEMATICS AND THE SCIENCES

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ABSTRACT

Environmental issues can provide an excellent way to connect mathematics with the sciences. 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 introduce environmental materials, some adapted from outside sources and some 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 dozens of 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. Preliminary data were collected in the fall of 2001, and a first assessment of the project's goals will be completed in the late spring of 2002.

Key words and Phrases: Interdisciplinary mathematics, discovery-based learning, environmental science

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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. 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 for students [10]. Like faculty at many other institutions across the country, 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 campus. The project described here focuses on using environmental issues to bridge mathematics and the natural sciences.

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 [19]:

> 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 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" (or "stovepipes" as Rita Colwell [6] aptly called them) 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.

We want 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 experiential, connection-building learning activities is well-documented, and many successful reforms have been implemented at schools across the United States. Relevant activities in mathematics range from the adoption of reform calculus texts and courses ([21], [15], [2], 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 ([3], [13], [8], for example); to the offering of programs, such as that at Evergreen State College [9], where the traditional role of a course has been replaced by wholly integrated semesters of study.

Lacking both the student body and the faculty resources to offer an alternative track to traditional calculus or science sequences, and restricted by the state university system from overhauling the overall course structure, we strive toward smaller successes within a fairly traditional 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. In this endeavor, the Honors College is taking a two-fold approach to integration within a fairly traditional curriculum. First, faculty are working to weave an environmental thread through the introductory mathematics courses: precalculus, calculus and statistics. Second, the college is offering a series of new one-credit courses that are team-taught and that focus on the analysis of data from student and faculty science projects using increasingly sophisticated tools. These are described in more detail below.

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 January 2002, the college enrolled approximately 240 students at the freshman, sophomore and junior levels. At full capacity (Fall 2005), the Honors College will enroll 500-600 students and employ some 50-60 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 The Courses

3.1 Introductory Mathematics and Statistics

To create stronger connections among the introductory science and mathematics courses, we are integrating in the introductory mathematics courses materials which emphasize environmental science. 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.

For statistics, educators are nearly unanimous in their encouragement for students to work with real data, and preferably student-gathered data [14], [4], [17], [5], [24]. As long-term research projects are incorporated in the science program, we will naturally develop a large bank of environmental data sets that can be used for examples and projects in the introductory statistics course. So far, students in statistics have worked on projects analyzing pollution levels in Lake Erie (materials adapted from [22]), aggressive behavior in the Giant Damselfish and characteristics of Abacoa's gopher tortoise population, the latter two projects based on data collected by biology professor Jon Moore.

In the precalculus course, students work on a series of projects in which they model the physical characteristics, individual growth, and population growth of the gopher tortoise population in Abacoa, employing linear, quadratic, exponential and logistic models. We have also employed materials from Mooney and Swift's text [16], in which students investigate migration patterns of squirrels.

At the calculus level, our efforts are supported by the Harvard Consortium text [15], 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* [18], 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 [20], 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.

3.2 Current Linked Courses

To help students make connections between their science experiences and mathematics, we are developing new "linked" courses. In its planning document, the Honors College emphasized the importance of establishing connections between disciplines and created linked courses to provide a structure for making these connections. 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 topics which cross disciplinary boundaries.

Data Analysis. The Data Analysis link provides students with the opportunity to statistically analyze 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. To analyze their data, students are expected to make appropriate choices in the application of statistical methods. 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.

For example, the current Data Analysis course is working with data concerning 1100 sea turtle nests on an 11-mile stretch of beach directly east of the college. Biology professor Jim Wetterer and some of his students collected data on the species of sea turtles, 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, and the relationship between the presence of ants and number of live hatchlings. The students will soon discuss multi-linear regression (a technique that is new to them), then use what they have learned to build a model for predicting the percentage of live hatchlings from a nest, based on the variables they determine are important to the model. Later in the semester, students will analyze data sets individually (data from their own projects, or from a project of a faculty member in their chosen discipline), present their analyses to the class for discussion and refinement, then write a final paper discussing their findings.

Environmental Science Seminar. The Environmental Science Seminar is designed to introduce students to multidisciplinary collaboration and peer-review. 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 identifying a senior thesis project), while senior year participants present results from their ongoing research projects. This year, because we do not yet have seniors, a portion of the seminar is dedicated to faculty discussing their current research, emphasizing potential student projects. The seminar is attended by faculty members and students in chemistry, biology, mathematics, physics, economics and psychology.

3.3 Future Linked Courses

Mathematical Modeling. The modeling link, first to be offered in the Fall of 2002, will require significant planning and close cooperation among participating science and math faculty. For a student to enroll in this course, it will 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 (or, indeed, any number of other elements, especially redox-sensitive elements like iron and manganese) 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 [1]. In any one-semester modeling link, we expect that students will be introduced to several types of modeling—steady state box models, non-steady state box models, chemical equilibrium models, population models—depending upon the projects carried out in chemistry and biology. Examples of environmental modeling materials abound, including the rich introductory texts of Harte [12], Mooney and Swift [16], and Hadlock [11], all of which are largely accessible to students with a background in calculus, which will be a prerequisite for the Modeling link.

Geographical Information Systems (GIS). Beginning in Fall 2002, the Geographical Information Systems (GIS) link will be offered primarily for students in their junior year, and will 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.

For example, students may use GIS to 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, increased human population and traffic may directly or indirectly impact not only the population of tortoises, but also where they burrow and graze [23]. As another example, data collected for chemistry projects on fertilizer application could 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 Assessment

At the time of this writing, the project is just beginning its second semester, and the data available are very preliminary. In the late spring of 2002, after our first round of evaluation, substantially more data will be available, including comments from outside evaluators who will be reviewing student projects, testing instruments, faculty and student reactions and criticisms, and the overall contribution of the project to the mission of the college. Thus, a more substantial interim assessment of the project will be presented at the conference.

The data currently available are student survey responses from the beginning and end of project-related courses in Fall 2001. 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 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, and two of the three other statements specifically geared towards mathematics and statistics generated similar differences in responses.

Our sample was relatively small, and many students had completed only one course of our 4-course requirement (2 mathematics, 2 natural sciences, including one with an environmental emphasis), so while the data are by no means conclusive, we are encouraged that our courses seem to be contributing to students' increased belief in the interdependency of mathematics and the sciences. By the end of the sophomore year, when most students will have completed the 4-course mathematics and science core requirement, we hope to see more conclusive data.

5 Challenges

Specific to mathematics and statistics courses, a major challenge is getting the students involved in hands-on data collection. Unlike most science courses, which include a three hour lab in addition to three hours of "lecture," mathematics and statistics courses generally meet three times each week for a total of four hours. The short class periods make field work nearly impossible, and a lack of laboratory space makes it difficult to gather data in the lab. Thus, we have been unable to employ as many hand-on activities as we would like. The students still have opportunities for discovery in many of the projects, but the discovery is structured, with data provided instead of gathered.

Overall, the biggest challenge to the project may be the disciplinary training of the faculty members involved. Universally, we are willing to take the intellectual risks necessary to teach and learn outside of our disciplines, but many are concerned about the consequences of these choices at tenure and promotion time. Out of eleven mathematics and science faculty members involved in the project, only one has tenure, so the risk to individuals is considerable.

6 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 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.

A collection of links to materials we have adapted or adopted for use in statistics and calculus, as well as some of the materials the college has developed, is available at `http:www.fau.edu/∼sfitchet/ccli/ccli.html`.

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