A New Paradigm in Integrated Math and Science Courses

Finding Common Ground Across Disciplines

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This article describes an interdisciplinary curriculum designed by the authors that connects math, science, and technology with the lives of their students. Changing students' understanding of science required building connections across disciplines, building support among colleagues, and building trust with the administration—an effort that transformed their institution.

In the fall of 1996, Drury University in Springfield, MO, introduced a new integrated mathematics and science curriculum required for all nonscience majors with the goal of producing graduates who are literate in mathematics and science. The impetus to develop this new curriculum was twofold: like many others, we believe that science and mathematics literacy will be essential for citizens in the next century, and that the current pedagogy of mathematics and science education has proved inadequate at developing such literacy. This paper describes both the curriculum we developed to address these concerns and the process that led to our new courses.

New courses tend to emphasize content and structure and exclude considerations of process. As we worked to build a new approach to science and math education for our nonscience majors, we discovered the importance of the planning process itself, as well as evaluation that allows for revision and improvement. While working toward an interdiscipli-

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nary approach to math and science education, we emphasized our common ground, included more colleagues in the design and implementation, and kept our administration informed of our effort. We hope that our experience, driven partly by chance and partly by design, may be helpful in guiding those beginning similar reform efforts.

Impetus for Reform

Our experience at Drury confirms that nonscience majors are uninterested in classes that present science as an assortment of facts, not as a dynamic and evolving discipline (Tobias 1992; Project Kaleidoscope 1991; AAAS 1990a). Too often these lecture courses superficially cover huge amounts of factual material, which results in short-term memorization by students with little understanding or retention of material, even among students who receive high grades (Rubinstein 1994).

Students have difficulty relating science information to the world around them, which undermines their development of a "holistic" understanding of nature. This is exacerbated by the narrow disciplinary boundaries of most science course offerings (PKAL 1991). We have found that traditional courses do little to rekindle students' native curiosity about the natural world, which has often been anesthetized by previous unimaginative science education.

Similarly, the pedagogy used in most undergraduate mathematics courses has been highly criticized (NRC 1989; NRC 1991; AAC 1990; Steen 1992). Lecture and rote problem solving does little to develop quantitative reasoning skills and often only serves to heighten a sense of math anxiety. The problems assigned connect poorly with students' experiences, reinforcing a belief that mathematics is irrelevant to their lives. Also problematic is that this pedagogy is not well suited to the learning styles of women and minorities (Tobias 1990).

In response to these concerns, we developed a new curriculum for nonscience majors, which replaced our traditional requirements of a single mathematics course (typically college algebra) and any two science courses (such as earth science, which did not include a laboratory). Our new curriculum was designed to develop literacy in both mathematics and science, stressing the relevance of mathematics to the physical world, the interconnected nature of the sciences, and participation in research.

The Planning Process

The planning process for this curriculum was lengthy and difficult, but ultimately rewarding. When we talk with others about our work, one of their first questions is often, "How did you get the entire science and mathematics faculty, the administration, and faculty outside the sciences to pursue this radically different approach to education?" Our stock answer is, "It wasn't easy." It took many years to bring this curriculum to fruition.

Planning a new approach to science education necessarily involves a large portion of the campus. We eventually developed a consensus among faculty and administration, beginning from a number of different starting points. Several faculty members were already interested in changing our approach to general science education, while others had been successfully experimenting with group work in mathematics courses. Our administration was increasingly interested in the role of science in our institution. As we proceeded, we knitted these elements together into a solid consensus for changing both what we teach and how we teach it.

It is difficult to pinpoint when we began the planning process. Faculty discussion on the need for new facilities had led the administration to consider renovating and expanding the existing science building. One important event in moving beyond this was Drury's participation in a 1992 Project Kaleidoscope meeting on building new science facilities. Drury's team included our president, Dr. John Moore, and our dean and vice president of academic affairs, Dr. Stephen Good. Dr. Moore became convinced that the


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best liberal arts institutions need first-rate science programs and facilities, and he initiated a major effort to build and equip a new $15 million science facility. Dr. Good became very interested in new trends in science and mathematics pedagogy and became proactive in encouraging the mathematics and science faculty to develop a more integrated approach to the education of nonscience majors.

With this, Drury began a close working relationship with Project Kaleidoscope (PKAL). This, along with our long-term connection with the Council on Undergraduate Research, greatly influenced the development of our new curriculum and led us to emphasize both interdisciplinary teaching and research as a teaching pedagogy.

The college was also planning a new general education curriculum, an outgrowth of a new mission statement. During this time, the faculty discussed what sort of education would prepare our graduates to be productive citizens in the twenty-first century. We were fortunate to have a number of convocation speakers on campus (such as Nobel Laureates Leon Lederman, Johann Deisenhofer, and Thomas Cech, as well as prominent author Sheila Tobias) who reiterated that educated citizens would require a much stronger background in science and mathematics. Their combined message helped solidify belief among members of the science division that we needed to increase the general education requirements in mathematics and science.

Their arguments also aided us as we began the difficult task of convincing faculty outside of our division of the need to increase these requirements. In December 1993, Drury's faculty approved a new general education curriculum, which increased science and mathematics requirements from nine to 12 hours, and gave our division the task of developing courses to fulfill these requirements.

In addition, seven of the 17 members were newcomers to the mathematics and science division. These younger faculty provided a strong core that was less wedded to old pedagogy and willing to consider innovative curricular options. Also, a few senior faculty came forward in support of radical change of the traditional pedagogy. This coalition of junior and senior faculty was optimistic about the potential success of a new interdisciplinary curriculum. This group's enthusiasm provided the momentum required to overcome the healthy skepticism of other faculty, and led to a division-wide belief that an innovative and interdisciplinary curriculum was both possible and preferable.


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In May 1994, the mathematics and science division held a two-week workshop to begin planning the new courses. At that time, there were four full-time faculty in mathematics, six in biology, four in chemistry, and three in physics. To encourage participation, the dean agreed to provide stipends of $500 for faculty. Although the amount was small, it indicated a degree of commitment by the administration and by faculty members to this project. Faculty were concerned that developing a new curriculum needed to be seen as substantial work above and beyond current commitments. Devoting summer time and salary to this effort convinced several people that would be the case. In fact, 15 of the 17 faculty in the division participated in this workshop.

Prior to this workshop, participants read *Science for All Americans* (AAAS 1990b), *What Works: Building Natural Science Communities* (PKAL 1991), *The Liberal Art of Science* (AAAS 1990a), and *Revitalizing Undergraduate Science* (Tobias 1992), which steered the direction of our discussions and deliberations. At the workshop we discussed our philosophies of mathematics and science education and defined expected student outcomes, both what should students know (content) and what should they be able to do (process).

In retrospect, we believe our success in developing this curriculum was directly tied to the way in which these discussions proceeded. All too often, curricular discussion can devolve into struggles to claim and defend turf or arguments for the priority of one discipline over another. We avoided this problem by focusing the discussion on what our areas had in common: how we view nature, what view of science our students should have at the end of their studies, and how we connected to each other. It was surprising how much our disciplines shared, and that realization committed us more strongly to developing an approach to science rather than to our separate disciplines.

While we still disagreed on how

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to structure our 12 hours, the majority agreed that our primary goal was to help nonmajors develop mathematics and science literacy. More than anything else, the group unified around a suggestion that the final component of this curriculum should be a research course, proposed by the most junior member of the group who was to join the chemistry department in the fall.

As a result of this workshop, the science and mathematics division became a unified group of faculty with a common vision. Almost all of the division participated, allowing significant time for both professional and social interaction. This workshop improved faculty morale more than any other single event. Reaching consensus concerning the elements of this curriculum was most rewarding and helped to dissolve interdepartmental friction.

This new unity bore immediate fruit. The college was preparing a grant proposal for a new facility. The administration initially suggested that the new building house two of our four departments, with the other two remaining in the current (renovated) building. We argued strongly that any new building should house all four departments since we would be planning and teaching the new curriculum together. We convinced the administration and rewrote the proposal to highlight developments from our workshop.

Another significant outcome was the decision to seek funding from the National Science Foundation (NSF) Course and Curriculum Development program. NSF funded our proposal for two years beginning in May 1996, with a combined NSF/Drury matching budget of $216,000. Support from NSF was crucial in developing and implementing our plans. We believe that our commitment to the project was evident in our proposal, and that initiative helped us to unite our administration and faculty behind our vision. Trying to effect change by seeking support at the outset is a much more difficult way to proceed.

In addition, the process of grant writing contributed significantly to the success of our curriculum. In discussing, developing, and writing this grant, we strengthened the connections made during our workshop and cemented the commitment necessary to make this curriculum work. In fact, we were prepared to go forward even without NSF support because the additional year's work made clear what needed to be done and how committed we were to doing it.

In summary, we believe that three elements are critical to a successful planning process: building connections between departments, broadening the number of participants, and ensuring support from the administration.

The Integrated Curriculum

Our integrated curriculum for nonscience majors consists of the following three courses:

- Mathematics and Inquiry (MATH 203): a three-hour course;
- Science and Inquiry (NSCI 251) a six-hour course;
- Undergraduate Research (NSCI 361) a three-hour course.

Mathematics and Inquiry (MATH 203)

In the fall semester of 1996, eight sections of Mathematics and Inquiry (MATH 203) were taught to approximately 180 students. Six or seven additional sections of this course have been scheduled in each subsequent semester, with approximately 150 to 180 students enrolled.

The purpose of this course is twofold: to prepare students for the following science sequence and to upgrade the mathematical literacy of all students. Emphasis is placed on defining and setting up problems, understanding the process of problem solving, and demonstrating how necessary information can be obtained from text materials, resource individuals, and computer resources.

The highlights of our new course include:

- Material that is a combination of algebra, trigonometry, statistics, and calculus;
- Student work in small groups to complete word problems projects;
- Written essays concerning the nature and relevance of mathematics;
- Oral presentation of word problems;
- Exams and a comprehensive final composed predominately of word problems;
- Use of *Derive* graphic software.

The material covered through seven projects includes:

- Linear, polynomial, logarithmic, exponential, and trigonometric functions and their applications;
- Variation, permutations, combinations, and elementary statistics;
- Use of limits to find the derivative.

Students also write essays after completing readings on math anxiety, the relevance of mathematics, and the nature of mathematical truth compared with scientific knowledge. For the liberal arts student, these types of assignments help define mathematical literacy.

Science and Inquiry (NSCI 251)

Science and Inquiry is a six-credit hour, interdisciplinary course that is team-taught by faculty from each of the three sciences. We have taught this course each semester since the spring of 1997, with enrollments of about 80 students. Required texts include Trefil and Hazen's *The Sciences,* and Watson's *The Double Helix.*

The course is designed to emphasize the problem-solving aspect of science and the interdisciplinary nature of many of the problems we encounter. One of our principal goals is to help students understand that science is a process for understanding our universe and improving the quality of human life, and not the memorization of apparently unrelated facts. The laboratories are designed to give students first-hand experience with experimentation and open-ended investigation while discussions help connect science with the lives of the students.

To help students see that science involves many different abilities, we incorporated several different types of work into the course. The course is writing intensive, with each student composing three to four reaction papers on readings and discussions and choosing a topic to investigate for a research paper. We use activities to reinforce the role of mathematics, and tests and quizzes to tie the material we cover in class to the real world. With the many different forms of assessment, a weakness in one area need not prevent students from doing well.

The course was divided into three modules: (1) the nature of science; (2) human genetics and DNA; and (3) light and its applications. The first unit lasted three weeks and introduced the scientific method, using the development of atomic theory as an illustration. The second and third units were five to six weeks long. These modules can be replaced with others as the course evolves. We developed these three modules to address the definition of science literacy.

The DNA unit began by making the connection between human characteristics and DNA. The classic experiments of Griffith, Avery/McCarty/McCloud, and Hershey/Chase, which established DNA as the genetic material, helped illustrate how science proceeds. Next, we discussed the chemical structure of DNA and how that contributes to its function. We read Watson's *The Double Helix,* not only to give students the exciting story of uncovering DNA's structure, but also to continue our discussion of the nature of science. We continued with the processes of DNA replication, RNA and protein synthesis, and the structure and function of proteins, and finished by looking at DNA technology, possible treatments for human disease, and their ethical implications.

The section on light began with waves, how light shows the diffraction and interference behavior characteristic of waves, and the photoelectric effect, which shows the particle nature of light. To understand Einstein's revolutionary explanation, students plotted and analyzed data collected in Robert Millikan's original investigations. We also examined how chemists and physicists use light to understand atomic structure and the chemical composition of materials. Two weeks were devoted to how light is used to determine the properties of stars and the size of the universe. In the laboratory, students measured the age of the universe by repeating Hubble's measurement of the redshift of nearby galaxies, using the excellent simulation by the CLEA project at Gettysburg College. We concluded the unit with the physiology and chemistry of human vision.

Every lab was designed to explore and extend the ideas encountered in the lecture and discussion sections of the course, and included the following experiments:

- Making Ice Cream: Using the Scientific Method;
- Passing Genes: Transformation of Bacteria;
- DNA Isolation and Electrophoresis;
- Modeling the Hydrogen Atom;
- The Hubble Redshift Distance Relation.

To strengthen their understanding of lecture and laboratory concepts, students divided into small-group sessions to discuss current events and ethical issues related to science and technology, such as the Hale-Bopp comet, the possibility of human cloning, and *The Double Helix*. Students also considered specific connections to mathematics and the MATH 203 course. For example, students used data from the DNA lab to study the exponential relationship between DNA length and its migration during electrophoresis.

Undergraduate Research Experience (NSCI 361)

The Undergraduate Research Experience course was offered for the first time in the fall semester of 1997. In this course, students apply the skills and knowledge acquired in the two preceding courses to solve scientific problems. We typically offer four to six variations on this course each semester taught by faculty drawn from physics, chemistry, biology, exercise & sports science, and behavioral science. Some of the courses have included:

- Research in CCD Astronomy
- Diabetes and Cell Membrane Research;
- Determining the Effectiveness of Multimedia in the Classroom;
- Research in Exercise Physiology;
- Organic Chemistry of Household Products;
- Research in Planetary Astronomy;
- Investigating the Aquatic Ecosystems of the Ozarks;
- Research in Human Memory and Learning;
- Research in Human Genetics.

To foster collaborative learning, students work in teams of two to four under the direction of a science faculty member to design an experiment and use the scientific method to investigate questions generated either by the students or connected to an ongoing faculty project. Students write up research results in the format required for publication, make an oral presentation, and present their work in a poster session held at the end of each semester.

Curriculum Evaluation and Revision

One of our goals is to evaluate the effectiveness of this curriculum and its unique pedagogical elements. To do this, we developed a comprehensive assessment protocol, including a student attitudes survey, a scientific interpretation test, a math literacy test, focus groups, and an outside evaluation program. This evaluation enabled us to clearly identify the strengths and weaknesses of our curriculum, where students were having difficulty, and where they were excelling. More significantly, our assessment protocol provided a mechanism for revising our curriculum to meet our educational goals.

We will provide a detailed description of this evaluation and revision process in a subsequent paper. However, it is important to realize that the information provided by such a process is important for improving the courses, not just determining their effectiveness. We used what we learned from student focus groups, external evaluators, and student evaluations to significantly revise our courses, and substantially improved them in the process.

Evaluation is an integral component of curriculum development, and much of our success can be attributed to feedback provided by this assessment. We have a much better understanding of the attitudes our students bring to our classes. The process allowed both student and external evaluators to offer healthy criticism, helping us to modify and improve our courses. This feedback was often very positive and encouraging, which helped maintain faculty morale. Also, we learned a great deal about the components of effective evaluation, allowing us to further refine our assessment protocol, which we believe will also be valuable to other educators. In addition to improving our curriculum, our evaluation confirmed that we are making significant progress toward our goals of mathematics and science literacy for our students.

Conclusion

The mathematics and science faculty at Drury University has developed a unique and ambitious new curriculum to significantly improve the math and science literacy of our nonmajors. This curriculum required us to formulate a new paradigm for educating all of our students, emphasizing the interconnectedness of all disciplines in understanding our world. The pedagogy of this curriculum makes use of material that is relevant to student's lives, contains an integrated laboratory component, emphasizes small group projects, and engages all students in a semester of scientific research.

Planning and implementing this curriculum has been difficult yet rewarding. The process united our faculty, focused our sense of purpose as educators, and most importantly, benefited our students. While formidable tasks remain for this curriculum to function at its highest level, we are extremely optimistic about its future. With our intensive assessment protocol we are already learning a great deal about our progress and have begun revising our courses. As this ongoing evaluation provides additional information, we believe that this curriculum will continue to improve.

We are extremely grateful for all of the help that we have had along the way, both from the NSF, our administration, and from the many individuals mentioned in this paper. We hope that our experience will be useful to others embarking on curricular reform, whether for majors or nonmajors, within a department or across departmental boundaries.

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Note

An instructor's manual, which details the laboratory and discussion exercises, problems and projects, and examination questions used in these courses, is available upon request from the authors.

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