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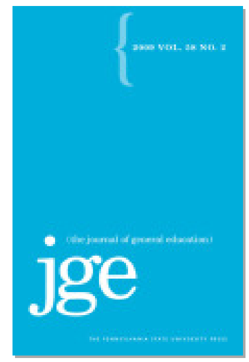
The Journal of General Education, Volume 58, Number 2, 2009, pp. 85-105
(Article)

Published by Penn State University Press
DOI: https://doi.org/10.1353/jge.0.0038



Reform in Undergraduate Science, Technology, Engineering, and Mathematics: The Classroom Context

Frances K. Stage and
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Research that documents the need to change the way science, mathematics, engineering, and technology are taught at the undergraduate level has prompted a number of institutions of higher education to create initiatives to improve the learning of science and mathematics by all students (Colleagues Committed to Redesign, 2005; Drew, 1996; Jacobson, 2006; Kinzie, Stage, & Muller, 1998; National Science Foundation [NSF], 2000, 2005; Rosser, 1997; Seymour & Hewitt, 1997; Schiebinger, 1999; Yadav, Lundeberg, DeSchryver, & Dirkin, 2007). Institutions of higher education have adapted new curricula and pedagogical approaches to broaden the attraction to, and success with, science and mathematics. Programs to revitalize the undergraduate learning experience transcend traditional disciplinary boundaries, promoting excellence in science, technology, engineering, and mathematics (STEM) education; increasing the participation of underrepresented students in STEM fields; and improving science literacy among students majoring in fields outside STEM.

In the past reforms were directed at undergraduate teaching and the role of introductory courses in setting the tone for undergraduate science. For example, several institutions adopted "calculus reform" projects that more closely aligned calculus instruction with theories of how students learn. Springer,

JGE: THE JOURNAL OF GENERAL EDUCATION, Vol. 58, No. 2, 2009

Stanne, and Donovan (1999) and Treisman (1992) found evidence of effective small-group learning in undergraduate STEM courses. In science classes the emphasis turned to empirical discovery, in lieu of static recitation of science facts, and the incorporation of more hands-on learning and open-ended tasks (Alaie, 2008; Bowman & Stage, 2002; NSF, 1998, 2000; Thelk & Hoole, 2006). These innovations are geared so that students will develop more favorable attitudes toward learning in science, persist in STEM courses, and possess technological literacy and knowledge and understanding of science to address the requirements of the new century.

Faculty, students, and administrators at institutions of higher education have worked as partners to promote excellence in STEM education through curricular and pedagogical initiatives. Although such initiatives have been recognized as innovations in undergraduate education, they have also been difficult to implement, propagate, and sustain (Eisenhart, Finkel, & Marion, 1996; NSF, 2000). In addition, their influence remains relatively isolated, often to within the department itself. This isolation reflects the fact that institution-wide reform occurs sporadically in higher education.

In an effort to understand what works in undergraduate science education and to facilitate dissemination of information with a view to modifying policies and practices, we embarked on a research project with programs engaged in institution-wide reform of STEM courses. The purpose of this article is to advance understanding of the contributions of specific reform efforts and identify programmatic aspects that work. One of the major focuses is to incorporate research on how students with diverse learning styles and cultural and academic backgrounds learn and to reconsider traditional goals and pedagogical approaches. Here we report on the modifications in teaching and learning, including the incorporation of active learning and peer teaching, use of authentic contexts, and emphasis on collaboration and interdisciplinary connections, at three differing campuses.

Conceptual Framework

We began by conducting a broad examination of exemplary reform efforts in undergraduate science education while incorporating a focus on the particulars of each case. We used theory and existing frameworks as heuristic devices to think constructively about the data. Contemporary models and theories on undergraduate teaching and learning served as one useful framework in our study. We have seen an emphasis on increasing active, experiential, and hands-on learning; peer teaching; collaboration; faculty–student interaction; and the importance of assessment in undergraduate education (NSF, 2000;

Stage, Muller, Kinzie, & Simmons, 1998; Thelk & Hoole, 2006; Williams, Oliver, & Stockdale, 2004). These theories and models suggested that the most effective undergraduate learning is active, cooperative, and demanding. In addition, a body of evidence suggests that employment of such active learning strategies results in enhanced student learning and increased student satisfaction.

In contrast to the learning-centered paradigm, undergraduate instruction in STEM often features instructional techniques wherein knowledge is transmitted by the expert teacher to students via the lecture format, a focus upon disciplines leading to a fragmented view of science, cookbook laboratory assignments, and an emphasis on a "scientific concepts first" approach (Kyle, 1997; McGinn & Roth, 1999). Although the predominant ideology among science educators is that hands-on experience, particularly laboratory work, is at the heart of science learning, there is little evidence that this approach effectively facilitates student learning (Hodson & Bencze, 1998; Kinzie, 2002; Kyle, 1996; Springer et al., 1999). The long-standing nature of these practices has raised concerns about the possibility of successfully infusing active learning strategies into the STEM curriculum. However, the imperative to improve undergraduate education and the emphasis on science for all students intensify the call to reform teaching and learning.

From literature focusing on frameworks and theories of learning (e.g., multiple intelligences, social cognitive theories, motivation theories), Stage et al. (1998) have identified six general practices that promote learning for college students. Table 1 provides science examples for those practices.

TABLE 1 Practices That Promote Learning for College Students with Science Examples

Practice	Example
Social Learning Experiences	Peer teaching, group projects, partnered tasks
Varying Instructional Modes	Site visits, Internet searches, demonstrations
Varying Student Performance Expectations	Presenting findings, enacting processes (measuring, coding, classifying)
Providing Choices	Students choose assignments from a range of options
Sociocultural Situations and Methods	Assignments focused on community or national issues (drought, biological hazards, etc.)
Course Projects Situated in Diverse Communities	Chemical contamination of rural water, asthma in inner cities

Social learning experiences, particularly those that promote group development of knowledge, allow students to observe peers modeling successful learning: for example, peer teaching and group projects where students can be encouraged to emulate other students. *Varying instructional modes* to deviate from lecture format, such as visual presentation modes, site visits, use of the Internet, and demonstrations, creates a more active classroom and can capitalize on a variety of ways of learning. *Varying student performance expectations* shifts assignments from merely individual written papers and tests to work that includes performance of actual work site tasks, group analysis, writing, and presentation. This style of learning mimics the style of work conducted in many science labs. *Providing choices* for tasks and topics, for example, giving students a choice from a list of projects, allows them to focus on a topic of personal interest. A choice between a written report and a class presentation allows students to capitalize on personal strengths. *Sociocultural situations and methods* use real-world problems such as global warming or biological hazards to develop class projects. Such projects demonstrate the usefulness of science on a day-to-day basis. *Course projects situated in diverse communities*—inner cities or rural areas, the Amazon, along the northeast U.S. coastline, or villages in Indonesia—encourage students to think broadly about the role of science in the world.

Obviously, it would be difficult or impossible to incorporate all of these elements into a single classroom. However, if most college classes could incorporate just a few of the elements listed above, colleges would develop into more learning-centered communities and would move toward meeting the learning needs of a greater proportion of their students. Therefore, our examination focused on the extent to which teaching and learning experiences were modified to be more productive and rewarding for both students and faculty.

Methods

In the late 1990s, the NSF awarded eighteen institutions of higher education grants to assist in efforts to plan and initiate comprehensive changes in science, technology, engineering, and mathematics undergraduate education and to allocate institutional resources to accomplish reform institution-wide. These institution-wide reform projects exemplified new approaches in undergraduate STEM education and represented an important opportunity to explore systemic reform of undergraduate education. We studied several of those institution-wide reform projects in order to increase understanding of programs, to assess effectiveness, and to inform others of the results. We chose to focus on three programs that were selected through a series of eliminations. First, we included projects that proposed to make changes in both faculty and student behaviors in classes. Second, we wanted projects that had made progress toward their reforms. An outside evaluator for the reform grants helped identify projects fitting our specifications. Finally, we made contact with the project directors and asked for their cooperation. One potential site was eliminated at that point because of a reluctance to participate.

The three sites encompass differing campuses: an urban comprehensive university in the northwest United States we called Transfer State University (TSU), a small liberal arts college in the rural Midwest called Mid-Western College (MWC), and an urban campus in the northeast with a large number of at-risk students called Metropolitan University (MU). Mid-Western College was small enough to affect half the student body through changes to the two sections of one yearlong course called Planet Earth combining elements of biology, chemistry, statistics, and English, taken by first-year students with an optional follow-up course in the second year.

Reform at Transfer State University consisted of a variety of interdisciplinary courses offered at the junior year level because so many students were transfer students. Examples include a course combining technology with biology and one combining technology with geology. Each course met in a computer lab, used small-group projects, and incorporated the use of technology through electronic media and scientific data sites available on the Web. Student group presentations of final projects were Web based. Another example combined art and physics, and a fourth, biology and culture. The first two campuses forged change primarily through cross-disciplinary collaboration.

On the other hand, Metropolitan University created change by providing a central venue for faculty learning, discussion, and collaboration surrounding issues of student learning and classroom reform. Regular participants included a broad array of faculty departments at all levels. We spent the greatest amount of time at MU with faculty from geology, calculus, chemistry, and engineering, although we interviewed faculty from other STEM majors as well. By creating regular meetings in an atmosphere accepting of a variety of approaches to learning and creativity in teaching, the campus built a community of faculty who supported one another through change. At meetings faculty took turns presenting their reform experiences to their colleagues. Faculty described their reforms in basic science courses and in mathematics, engineering, and technology at higher levels.

The purposes of the three institutional projects included reforms to the undergraduate experience of science and engineering students as well as the experiences of nonmajors; increases in the engagement of faculty in undergraduate education; and the extension of successful pedagogical approaches, such as collaborative learning, hands-on experience in student teams, and active learning, in

STEM education. At all three sites, project developers built on a steady progression of curricular restructuring and pedagogical modification projects in calculus, chemistry, engineering, geology, astronomy, and computer science. In this article we focus on the changes that we saw in the undergraduate classes we visited.

Research Design

To gain an in-depth understanding of the undergraduate reform efforts, we employed a mixed-methods approach, incorporating both quantitative and qualitative data. A multiple case study design was employed to allow the development of an in-depth understanding of each site. We organized the case study around the reform projects' goal statements: to engage and motivate students in their science and engineering studies; to promote students' mastery of content as well as problem solving, communication, and teamwork skills; and to increase the engagement of faculty in undergraduate teaching and curricular reform. Specific research questions included the following: To what extent have the curricular initiatives been effective in transforming students' learning experiences in reform courses? Which faculty development efforts were most effective at engaging faculty in changing and improving their teaching strategies? To what extent did students engage in collaborative learning and increased interaction with faculty? Did interactions with faculty and among students contribute to students' sense of community and connection?

Site Visits

Through a total of eight site visits lasting two–three days to these campuses, we collected a broad array of data sources that include, but are not limited to, surveys, interviews, focus groups, classroom and laboratory observations, institutional records, curriculum guides, teaching portfolios, and meeting records. A typical site visit involved interviews with project directors, faculty, students (individually and in small groups), administrators, and community members. Observations from classes, laboratories, field-based labs, a teaching center, and faculty meetings were recorded as field notes. Quantitative data were drawn from institutional records (e.g., major declaration data, course evaluations, course grades, transcript records), and surveys of various student, alumni, and faculty groups were conducted in fall and winter 1999–2000. Documents including course syllabi, bulletins, meeting records, progress reports, and teaching manuals were also reviewed. The researchers include a senior faculty member and a doctoral candidate who was working on a dissertation using participant observation and focused on the introductory chemistry experience for undergraduate women.

Both of us had extensive experience conducting various types of campus audits and evaluations using focus groups and interviews.

Data analysis was conducted throughout the study in order to focus and shape the research as it progressed (Glesne & Peshkin, 1992). Prior to our first visits we reviewed documents related to programs and courses, and we arrived at our first campus visits ready to attend meetings with faculty groups working on teaching reform and to interview administrators, faculty, and teaching assistants. Additionally we observed classes and had informal conversations with student participants. The analysis was inductive, in that we simultaneously collected data and formulated ideas about issues in the case.

During the second and third visits we identified faculty and students for interviews, attended classes, and planned observations of field labs, student workshops, and faculty demonstrations (Table 2). Over the course of the study we attended meetings with over fifty faculty and administrators and conducted individual interviews with approximately forty faculty and administrators. Additionally, we interacted with dozens of student on each campus during our visits. We had numerous informal chats with individual and small groups of students—as they used technology to collect data for biology projects, waded in streams collecting mussels, created statistical charts of their observations, and engaged in other kinds of learning for their reformed classes. Additionally, we prearranged and conducted focus groups of students on all three campuses.

Our interpretive approach can be described as a form of thematic analysis that began with the identification of a few themes in the data, proceeded with the identification of preliminary evidence for the themes, and continued with the search for connections among the data, warrants, disconfirmation, and alternative interpretations (Merriam, 1998). By employing a case study design and an interpretive approach in analysis, we attempted to capture the experiences of participants to develop an in-depth picture of the case. Cross-case analysis resulted in several themes related to the topic of modifications in teaching and learning.

Findings

At all three institutions we found evidence that faculty were encouraged to devote significant time and creative energy to the teaching of undergraduates; strategies were devised to promote the success of students of diverse backgrounds, interests, and aspirations; faculty improved their teaching and implemented curricular changes; and faculty and students from many disciplines became involved in reform efforts. After only four site visits, analysis of the observation and interview data resulted in the emergence of several themes that we reconfirmed in subsequent site visits. Themes related specifically to pedagogy will be discussed

TABLE 2 Data-Collection Activities During Campus Visits

Campus and Semester	Faculty in Focus Groups	Faculty Interviews	Students in Focus Groups	Student Interviews	Teaching Assistant/ Student Leader Interviews	Class Visits	Administrator Interviews	Combined Meetings
Transfer State University, Fall		7	12	7	6	5	4	1
Transfer State University, Spring	6	2		5	2	2	3	1
Metropolitan University, Fall	14	4	5	3	7	2	3	1
Metropolitan University, Spring	7	5		4	5	1	3	1
Mid-Western College, Fall		5	7	4	5	2	2	1
Mid-Western College, Spring		3		8	4	2	2	1

extensively here: shifts in conceptions of teaching and learning and modifications to classes that reflected changes to those differing conceptions. The espoused philosophies about how learning occurs and therefore how classroom practices might change were obvious in statements made by program administrators and faculty and in documents used to describe or report about the programs. But they were obvious in their implementations in the classroom as well.

Shifts in Conceptions of Teaching and Learning

On all three campuses both faculty and students described their experiences with transformations from traditional classroom experiences to those that we termed learning centered (Stage et al., 1998). The most obvious were six that were evident on more than one campus:

1. A decrease in faculty authority in the classroom
2. Increased interaction with faculty
3. Learning as a collaborative process
4. The use of active learning
5. A focus on authentic contexts and practical knowledge
6. An increased emphasis on interdisciplinary connections

At two of the campuses we visited, we saw strong evidence of changes to the culture of teaching and learning on all six dimensions. On one campus, Metropolitan University, we saw much evidence of the first five within traditional courses. However, MU did not employ interdisciplinary courses and instead created frequent opportunities for faculty across disciplines, and especially mathematics and engineering and science, to interact outside the classroom.

Many of the philosophical changes in approach to teaching were explicit in materials describing the projects. For example, "Our programs focus on real-world and local issues of [this region] and try to incorporate elements from education research, precollege and undergraduate education, and community service" (TSU Center for Science Teaching Web page). Other times they were evidenced in stories, such as that told by an MU science faculty member: "When I was first teaching, I thought teaching was about presenting material without error. When students performed poorly my view was, 'Sorry if you are too dumb to see it.'" Then, expressing his current philosophy, he said, "I came here to help people. The harder I tried to improve my teaching, the more positive reactions I got from students. I now give good lectures."

Beyond espoused philosophy about changes in the classroom, we frequently observed the six approaches to learning listed above enacted by faculty, peer mentors, and students in classrooms. Because we viewed classroom behavior and course requirements as the preeminent criteria for evidence of change, we have focused on explicit description of those observations for analysis in this article.

We were given the opportunity to gain firsthand experience involving the shift in teaching through observation in classrooms, computer labs, and a field lab. This perspective offered a glimpse of the enactment of the shift discussed above. For example, the frequently used group learning experience served to decrease faculty-centered learning in the classroom because it empowered the student group members to seek sources of knowledge beyond those provided by the instructor. At the same time it fostered active learning and a view of knowledge acquisition as a collaborative process.

A Decrease in Faculty Authority in the Classroom

A conventional model of teaching assumes that the teacher holds the knowledge and it is his or her responsibility to deliver facts and conclusions to students (Palmer, 1998). In that model, the teacher is the sole authority in the classroom. By contrast, at all three sites we observed a move away from the typical patterns of teaching and learning to a model whereby not only students learned from faculty but faculty learned from students and students learned from peers and from more experienced students. Faculty shared their authority with students and engaged them in jointly constructing meaning rather than dispensing facts. Students, as they worked in their groups, became reservoirs of knowledge to be tapped, and they were encouraged to teach each other.

These shifts also were accomplished through a heavy reliance on peer mentors to extend teaching resources and to solicit feedback. Instructors used information generated by students as they worked on their particular projects to provide more materials for the class. For example, instructors set up laboratory experiences for which there were no preordained results. Additionally, based on constant feedback from students and peer mentors, faculty continually made alterations to their courses and to laboratory assignments. Finally, instructors actively encouraged students to disagree with them as well as to question existing models and "authorities."

At MU, a geology faculty member maintained the traditional lecture format yet provided a good example of diffusing authority. A student asked a question, and the professor was unsure of the answer. In front of the class he discussed possible answers with the lab instructor. The students saw her disagree with the instructor, offer an alternative hypothesis, and help construct a joint conclusion. By encouraging conflict or demonstrating that it is okay to disagree, differences in opinion can be viewed as a way to learn rather than as something to avoid.

The professor's deference to the lab instructor's expertise beyond his own not only served to model shared authority, it likely empowered all students, and especially women, in the class. In addition, a mathematics instructor and an engineering instructor created a combined syllabus for their separate courses that indicated the connection between the mathematics content and the engineering problems. The next year they taught a course that combined the material and the credits from the two courses into one class.

At MWC we watched the instructor and a student in the Planet Watch class page through a field manual together trying to decide which mussel had all the characteristics of the one the student had just found. At TSU we saw a student group in the Natural Science Inquiry course combing the Web for statistics about salmon counts in a local river for a project that they had developed with minimal input from their instructor. These student-developed questions were at the center of the inquiry in the class, and the answers they produced created the content knowledge for the course.

Similarly, at MWC students collected mussels from streambeds at field sites spread over a fifteen-mile radius. Because it was impossible for the instructor to visit more than a few sites per afternoon, authority was shared with peer mentors often the same age as the students enrolled in the class. On-site for three hours, the peer mentors made decisions regarding physical conditions for data collection, motivated reluctant students to enter the chilly water and participate in specimen collection, and prompted academic connections to the physical evidence that they found.

At TSU, graduate and undergraduate students from nonscience disciplines were paired with science faculty. They collaborated on the development of courses, taught class sessions, and developed course materials. For example, Complexity and the Universe was primarily a physics class but also a marriage of art, religion, and philosophy. We watched a slide presentation for the first day of class presented by the teaching assistant. She included slides of artworks that depict conceptions of the universe through the ages. Her presentation early in the course stirred students' imaginations and eventually prodded them to question their own preconceived notions of the cosmos. Two other classes combined technology and biology and technology and geology. Both were conducted in computer labs and taught by two instructors, each representing the individual disciplines.

With the increasing use of group projects in these classes, students developed their own research questions and found their own course materials—journal articles, newspaper articles, books, and Web sites that were most relevant to their own group's particular research question. Beyond assigning initial sets of core readings, the instructor had relinquished the control that comes with choosing all the readings for all students. Generating readings that were relevant to the question at hand became part of the task and the evaluation of the group work.

For a chemistry class, peer mentors gave grades to their group of ten students that amounted to 10 percent of their final course grade (see description below), giving them more authority in the class. During one sophomore-level science class at TSU called Natural Science Inquiry, we observed six groups of students spread out in the classroom at large tables or huddled around computer workstations in a small adjoining room. The instructor circulated among the groups, as students actively discussed, made graphs, read materials, and searched the Web. One group used a Web site to track increases in cigarette use in China; another read and analyzed responses from a survey of recreation camp users that had been posted on the Web; the third, recording salmon counts over time on a local river, explored relationships between the development of dams and habitat degradation. When we expressed amazement at the level of work the students were conducting in an introductory science class, a student asked, "Don't all schools have this?" We replied that most schools just require introductory biology, chemistry, or other science courses to fulfill general science requirements. The student then responded, "Isn't that boring because you can't apply it? I hate that."

Increased Interaction with Faculty

An unexpected benefit came from the students taking more classroom responsibility—faculty had more unstructured time in class. During much of the time in the classes we observed, instructors spent time with small groups of three or four students or with individuals. These interactions with faculty went beyond the usual kind of consulting that occurs for most students immediately before or after class sessions; they more closely resembled relaxed conversational interaction focused on the students' research projects. Although such interactions are important in establishing students' academic integration in college, research tells us that increasingly, students are unlikely to have such interactions with faculty. Because these faculty were not occupied at the front of the room for the entire class period, they had time to pay attention to individuals and small groups.

Learning as a Collaborative Process

Collaboration is based on the idea that learning is fostered through the social interaction of two or more learners (Mathews, Cooper, Davidson, & Hawkes, 1995). Probably the most pervasive characteristic of these campus reforms was the view of knowledge as a collaborative process. In nearly every class that we observed across the three campuses, collaboration was evident. The most obvious method for fostering collaborative learning was the use of group projects. However, the reforms did not stop there. Often peer mentors and sometimes class students were responsible for developing course materials. In the Natural Science Inquiry class described above, student groups extensively reviewed a problem and then formulated their own research questions that required analysis of data to answer. Their answers, and sometimes the processes they followed to arrive at those answers, informed the instructor as well as other students in the class.

We saw evidence of several types of collaboration: between and among faculty, between peer mentors, between and among students in small groups, and across these three groups as well. An engineering professor described changes to his course as a result of offering his class in conjunction with the calculus instructor. Additionally, faculty who taught interdisciplinary classes regularly modeled collaborative learning with the co-instructor for the course. At MU we visited a professor who met with mentors for the introductory course Nuts and Bolts Chemistry. We watched him, nine undergraduate peer mentors, and a graduate student "super leader" (who coordinated workshop activities) as they worked on activities for the next lesson. They used small sticks and colored balls to build tetrahedral models of chemical compounds. They discussed possible errors in construction and used a mirror to view a "twin" model with different chemical characteristics. The student leaders were enrolled in an accompanying two-credit leadership course. One student leader described to us his strategy of pairing up teams of weak and strong students within his group to maximize learning.

At MWC we watched as Planet Watch peer mentors Marie and Brynn worked and discussed the appropriate placement of a new group in the streambed after Brynn's group was displaced from their original location. Discussing the objectives of the lab, they jointly determined the best placement and then conferred with a third peer mentor, Chris, regarding placement of the flags to mark group boundaries. While students looked on, the three engaged in a discussion of the strategy behind positioning the flags. Brynn and Marie recalled how it was done last year and then deferred to Chris, who had less experience but had been more recently trained in marking the stream. With this ad hoc problem solving the peer mentors demonstrated collaborative learning to students enrolled in the class through their shared leadership and decision making. Additionally, the faculty member learned from the students' work that day; they found a mussel that was supposedly extinct. Upon return to campus, students excitedly shared with him in the identification process using their field manual, which had been constructed by peer mentors from textbooks.

In the group projects for the variety of classes we observed, students were expected to play a constructive role within their group and were evaluated on this. Competition was removed as an incentive and replaced with assessment based on group collaboration. Instructors and students talked about taking advantage of individual students' varying expertise. By listening to alternative perspectives and differing points of view about approaches to problem solving, group members developed deeper levels of understanding.

The Importance of Active Learning

One of the most interesting aspects of conducting the evaluation was watching students in the act of learning. The experience stands in sharp contrast to familiar learning situations wherein student slump in their seats, baseball caps pulled low over their eyes, and carefully write down anything they see on the overhead—reluctant to participate in any small-group class interaction that their instructor might encourage. Regular sights in these classes included several students hunched around a computer screen discussing data, students waist-deep in cool water digging mussels from a streambed, and students using colored sticks and balls to create models for understanding molecular structures.

A focus group of students from the Planet Watch class talked without prompting about the ways that the course capitalized on students' differing learning styles. One particular student described himself as someone who prefers being out in the field getting his hands dirty. The sort of lab experience spent digging in a stream for mussels matched perfectly with the way he preferred to learn. He declared, "For a hands-on person like myself, I learned a lot more. I could notice things up close." Another student in his group described her skills in "organizing text and designing a PowerPoint presentation"; she put these skills to use as her group worked on their class presentation. In addition, a student with artistic skills described using her expertise for designing illustrations for the presentation. Another student, with a more traditional learning style, was better at searching the Web and organizing materials for their paper and presentation. Mathematical expertise would also be useful to the group in analyzing and presenting the scientific data they collected. Clearly, the tasks for the group projects ranged broadly enough to accommodate a variety of expertise.

At MU, a biology professor showed us a model of a human elbow that he had constructed to show students how force changes as the angle at which the elbow bends to lift the weight changes. He said that in former classes he had used similes (such as using a jack for changing a tire on a car) to try to get students to envision the working of the elbow as a lever. Then he realized that most inner-city students had little experience with cars and tire changing. He became more conscious of his use of metaphors and similes in his classes, searching for those that might be relevant and familiar to all students. At TU the class Atmospheric Interactions investigated the physical composition and chemical interaction of clean and polluted air using the urban airshed as a study site. Students measured atmospheric temperature readings according to a protocol at various locations and at specific times of day. The highlight of the outdoor activity for many students was a scheduled rocket shoot that measured early morning temperatures at various heights from the earth's surface.

A Focus on Authentic Contexts and Practical Knowledge

An important aspect of these classes was the frequent incorporation of local problems and issues into the curriculum. In contrast with more typical introductory science classes where emphasis is often on memorization of a body of information, course emphases were on the development of problem-solving skills and the use of information tools to find answers to practical questions. Given the emphasis on authentic and current problems, ordinary texts were practically useless. The curricular materials for classes needed to be relevant and to track trends historically—thus reliance on the Web and current print media and even videos became integral and diverged widely from group to group.

On the smallest campus we studied, MWC, changes to the streambed habitat for fish and mussels resulted from construction of a dam and reservoir. Students' examination of that problem within the context of their class made connections to the state wildlife office, which was eager to accept their data. Additionally, important connections were established between campus and the local municipality. Finally, nonscience majors learned firsthand the connections between water chemistry and biology and the importance of informed decision making for citizens as well as local political leaders.

The Atmospheric Interactions class described above also provided an opportunity for students to seek practical knowledge in an authentic context. Students' data were analyzed and compared with Web- and other media-based information on global warming to allow students to decide whether global warming represents a real threat to life on earth. An introductory engineering design course at MU emphasized hands-on teamwork, collaboration, presentation, and computer work that got students into design early in the curriculum. The old curriculum delayed design experiences, using paper and drawing until upper-division courses, giving students little time to explore their chosen major in an active, authentic manner. For students who learn best with manipulatives or hands-on exploratory activities, courses that involve field labs or opportunities to be actively involved while learning may promote success and retention in the major (Johnson, Johnson, & Smith, 1991).

Increased Emphasis on Interdisciplinary Connections

Interdisciplinary courses draw on disciplinary perspectives and integrate insights through the construction of a more comprehensive perspective. In contrast to multidisciplinary courses, where faculty present their individual perspectives one after another and leave the integration to the students, an interdisciplinary approach, taught by an individual or teams, requires interaction between faculty in designing a course, examining underlying assumptions, and working with students to facilitate integration and more holistic understanding (Klein & Newell, 1996).

With the exception of MU, the predominant method used to reform existing course structures and approaches was the creation of interdisciplinary classes. This approach was accomplished through a variety of means: team teaching by faculty from two or more disciplines, combining elements of two or more courses, and inviting guest speakers to provide specific information needed to round out the course experience. Given the science-specific nature of the projects we studied, team teaching most often combined science with humanities faculty from disciplines such as political science (politics of science related decisions), English (written and oral presentation skills), and philosophy (logic and argument) or science with technology (use of Web sites, large data sets, and creation of Web presentations). Additionally, statistics and mathematics were important components of classes where students performed data analysis and presented that analysis through charts and tables.

As an example, in Planet Watch students spent one week learning presentation modes so that by the end of the semester they would more effectively convey information. Additionally, students from this course were able to take a follow-up course in education, where they developed curricular materials based on their previous semester's course projects. Students chose a target class level ranging from kindergarten through high school and geared materials appropriately. Students began to see learning more holistically rather than as isolated facts and methods to be used in one domain with little connection to another. They began to view knowledge, the processes for acquiring knowledge, and the processes for sharing and imparting knowledge as related across disciplines.

Conclusion

Through observation of reform in these undergraduate classrooms we recognized six changes from the traditional classroom approach: a decrease in faculty authority in the classroom, increased interaction with faculty, a view of learning as collaborative, use of active learning, use of authentic contexts and practical knowledge, and an increased emphasis on interdisciplinary connections. These approaches to teaching were enacted within the classroom through several methods. Among the most predominant were team teaching and combining courses from two differing disciplines, the development of community-based activities, heavy reliance on group projects, and a focus on active approaches for the tasks of those groups, with a particular emphasis on the use of the Web and other technologies to gather information that was current and relevant to the problem at hand.

There were some limitations to this study of STEM reform at three differing campuses. Because of travel considerations, visits to the campuses totaled just over sixteen days, limiting the number of events, meetings, and interviews we could conduct. Ideally a study with unlimited funding might include several visits over the course of a semester or year, such as Kinzie's (2002) study of women's experience of an introductory chemistry class. Additionally, we visited classes and met with faculty recommended to us by the project directors on these campuses. It is possible that there were faculty and students we did not meet who were disappointed with reforms in their classes and who could have provided other opinions about the projects. Nevertheless, we believe that the information we gleaned could be useful to those interested in reforming their own classes.

When we began to observe and to analyze what we had learned in these reform classes, we noticed the pervasiveness of technology. Initially we speculated that technology would be an important category for our findings. However, soon we realized that the application of technology in the courses we observed was important but not necessary for classroom reform. Most but not all the classes employed technology (Web searches, statistical packages, calculators, course Web postings, CDs) in some aspect of the assignments. Most often technology was an enabler for enacting a philosophy: a way of incorporating active learning, but not the only way; a way of using current contexts and practical knowledge, but not the only way; and so on. Technology was just another tool to be used side by side with more traditional learning tools, like books and videotapes, in a course based on new philosophies of learning.

Importantly, not every class we observed completely incorporated every element of these philosophies. In reading teaching and learning literature and learning about classroom reform, one might come to the conclusion that reform means wholesale change in the ways courses are conducted. However, many classes we observed probably differed only in small ways from the same class taught by the same instructor ten or fifteen years ago. Sometimes it was a change in the role of a lab instructor, the incorporation of a group project and peer mentors, increased use of classroom assessment techniques to determine what students know (Cross & Steadman, 1996), and inclusion of one course-long field experience rather than a series of discrete lab experiments. But every class we observed incorporated at least a few of these elements. The most important element, common throughout, was in the instructors' concern for and knowledge of students' needs.

Quotations from graduate student mentors involved in reform express the consciousness of the students and their needs best. We "use student assets for teaching." "Students come here with their suitcases fully packed. We ask them to unpack those suitcases," and we are "letting go of the need to cover content and teaching on a need-to-know basis." A biology professor reconsidered his classroom examples comparing the movement of the elbow with the movement of a tire jack when he realized that most of his urban students did not own a car. In this small way he demonstrated the overall self-reflection that prompts reform. Additionally, even twenty years ago, likely few young women had experience changing tires or identifying with similar examples used in engineering and other science classes.

One campus, MU, made changes with an approach that required no major curriculum revision process, which is often required for cross-disciplinary courses. The director of the center for teaching and learning educated individuals through seminars, by convening faculty groups to talk about teaching, and by bringing together two or three faculty members who shared similar problems or interests. While most of the reform at the other two campuses we studied came through sweeping changes that were funded by relatively small grants, the MU experience shows us that major reform can occur in a quieter way as well.

One unexpected observation was the degree to which the incorporation of graduate students and peer mentors served to democratize the college classrooms. By far, faculty whom we observed were white and male. But shifts in authority in the classroom, first to graduate students and then to peer mentors, also caused shifts in power and authority to women and ethnically diverse students. In fact, most often the demographics of peer mentors very closely matched the demographics of students in their classes. Reforms incorporating students in these active roles therefore served goals for placing demographically appropriate role models in positions that could encourage aspirations for students who might not otherwise have such role models. For those who lament the slow change in faculty demographics to match population demographics, this unexpected outcome is good news.

Reform efforts studied here were not absolute panaceas. Problems arose that, had the project directors not been single-minded and dedicated, could have threatened their success. Faculty spoke of the lack of relevant texts, which sent them scrambling to develop course materials from scratch. Others worried aloud about the loss of content for the sake of the group processes and projects.

Institutional structures sometimes posed barriers. Individuals from all three campuses mentioned that the standard teaching evaluation forms used by their institutions were irrelevant and sometimes penalized faculty engaged in reform. Sometimes students and faculty seemed rushed in their learning activities. Standard notions of courses as three-credit entities seemed counterproductive when two disciplines were combined and utilized team teaching. We wondered, Why not create six-credit courses? Credits generated could be divided across two departments and two faculty loads and fulfill two general studies course requirements for the students who enroll. Additionally, students would have more time for learning both process and content. These and other questions remain to be explored.

We want to emphasize that wholesale adoption of all these reform techniques would be difficult if not impossible. Given the infinite variety of backgrounds, skills, and styles that college teachers exhibit, reform must be tailored to individual classes and be consonant with the instructors' strengths and subject matter and students' needs. An idiosyncratic yet thoughtful approach to reform can yield benefits for student learning. Rather than making radical curricular change, instructors in the classes we observed relied on consideration of student-centered approaches to giving performance feedback, structuring class formats, and conducting performance evaluations. Research has shown that perceived salience of learning to future life experience is an important motivator to student learning (Simmons, 1996). Students who participated in these innovative instructional approaches expressed enthusiasm and perceived more meaningful learning experiences. Clearly the models of thinkingand practices presented here can provide models for change in a variety of disciplines.

NOTE:
Research reported in this article was funded through a grant from the National Science Foundation. Opinions expressed in this article are not necessarily representative of the National Science Foundation.

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