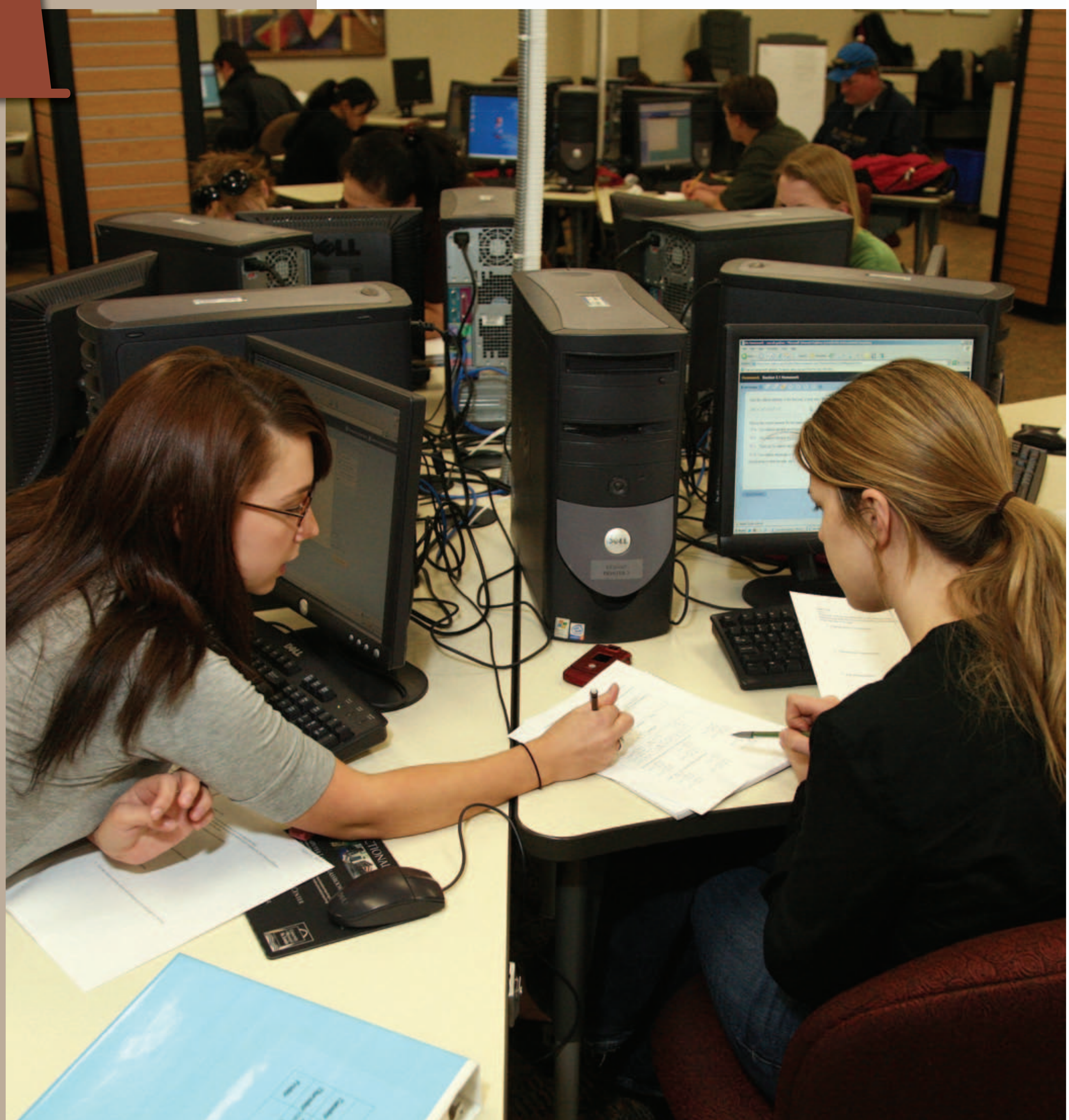
Summer August, 2008

Addressing the Crisis in College Mathematics 2008.pdf

Teresa Thiel, *University of Missouri - Saint Louis*
Shahla Peterman, *University of Missouri - Saint Louis*
Monica Brown, *St. Catherine University*

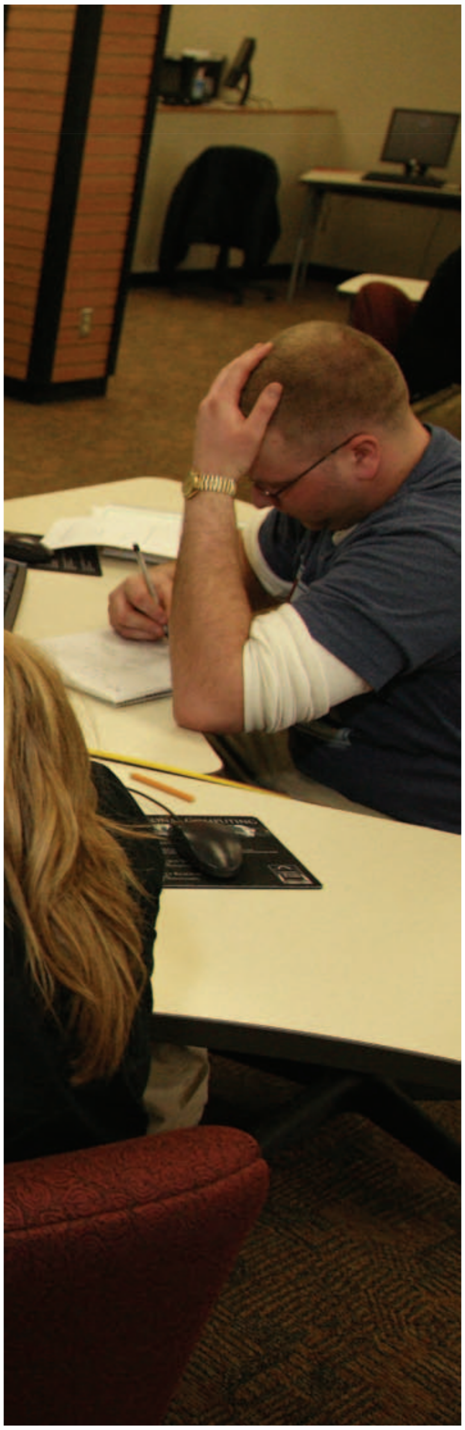
Addressing the Crisis



in College Mathematics

Designing Courses for Student Success

By Teresa Thiel, Shahla Peterman, and Monica Brown



For decades, Americans have taken for granted the United States' position as the world leader in the development of new technologies. The innovations that resulted from research and development during World War II and afterwards were critical to the prosperity of the nation in the second half of the 20th century. Those innovations, upon which virtually all aspects of current society now depend, were possible because the United States then led the world in mathematics and science education. Today, however, despite increasing demand for workers with strong skills in mathematics and science, the proportions of degrees awarded in science, math, and engineering are decreasing.

The decline in degree production in what are called the STEM disciplines (science, technology, engineering, and math) seems to be correlated with the comparatively weak performance by U.S. schoolchildren on international assessments of math and science. Many students entering college have weak skills in mathematics. According to the 2005 report of the Business-Higher Education Forum, "A Commitment to America's Future: Responding to the Crisis in Mathematics & Science Education," 22 percent of college freshmen must take remedial math courses, and less than half of the students who plan to major in science or engineering actually complete a major in those fields. Students in underrepresented minority groups, who suffer disproportionately in terms of weak math skills, are particularly underrepresented among college graduates in math, science, and engineering.

Teresa Thiel is a professor of biology and associate dean of the College of Arts and Sciences at the University of Missouri-St. Louis, where Shahla Peterman is a teaching professor in mathematics and Monica Brown is a lecturer in mathematics.

The result has been a decrease in the number of American college graduates who have the skills, especially in mathematics, to power a workforce that can keep the country at the forefront of innovation and maintain its standard of living. With the declining performance of American students in math and science has come increased competition from students from other countries that have strongly supported education in these areas. Many more students earn degrees in the STEM disciplines in developing countries, especially China, than in the United States.

Students' Success in Mathematics

College students' success in a course depends on many factors, including their ability and previous knowledge of the subject, the effectiveness of the instruction, and their motivation to work hard enough to succeed. Introductory courses, including many that satisfy general-education requirements, often pose a particular problem for students who are not interested in the subject or fear failure based on their high-school experiences. Students' low success rates nationally in mathematics courses are particularly damaging because these courses are a gateway to many majors and hence a major stumbling block to students' achievement.

At the University of Missouri-St. Louis, college algebra presented just such a problem. This course is required for several majors and is the prerequisite for calculus, the key course for students interested in math, science, business, and paraprofessional programs leading to advanced degrees in the health sciences. A fear of math and a lack of interest in algebra caused many students to avoid the course as long as possible, often delaying their progress toward a degree. In 2002, the success rate in college algebra (defined as a grade of C- or above) on our campus was about 55 percent. This problem is not confined our institution: There is substantial literature about college algebra as a barrier for many students, especially those from underserved populations.

To address this problem, in 2003 the Department of Mathematics and Computer Science began a major redesign of college algebra, with the support of the dean's office and the help of the Roadmap to Redesign (R2R) Program (http://www.highereducation.org/reports/pa_core/core.pdf). The R2R program provides models for high-enrollment courses that emphasize the use of technology to reduce lecture time and encourage active learning, continuous assessment of student progress, and techniques to keep students focused on the work necessary to succeed. Faculty at colleges and universities that have successfully used the R2R models in the redesign of a course serve as advisors to other institutions attempting similar changes.

> **The essence of learning math is doing math, rather than passively listening.**

The results of our redesign of college algebra were remarkable. Over a period of three years, student success increased from about 55 percent to over 75 percent, with no decrease in course rigor, as demonstrated by student scores on a final exam that included the same types of problems during the redesign period as before it.

We share here some of the details of that redesign and some of the principles that we learned that might be applicable to other courses in which poor student motivation is a major problem and a likely source of student failure.

Redesign of College Algebra

With the help of the R2R program and the advice of colleagues at other institutions, we chose a redesign plan that decreased lecture time from three 50-minute sessions a week to one session per week. We replaced the other two lecture periods with two computer-lab sessions where students took a hands-on approach to mathematics in a very supportive learning environment. The reduction in lecture time changed how we taught, since there was not enough time to present all the math principles and sample problems or to answer questions in one lecture a week.

But the essence of learning math is *doing* math, rather than passively listening. Students had to acquire information and work the practice problems on their own, aided by math software. The software, provided by textbook publishers, includes explanations, tutorials, practice problems, and guided solutions. It has been evolving over the last five years, providing more reliable scoring and a better interface for students and the instructors.

A key component of the redesign was the incorporation of software-based homework problems, which can be done either at home or in the computer lab. They are assigned every week, requiring the students to master a manageable amount of information one chunk at a time. Students can attempt the same type of problem repeatedly (the problems themselves change) in order to improve their homework scores.

The software gives them instant feedback, so they know immediately whether their answers are correct. If they are not, the software can guide them through the solutions and provide additional practice. This helps students understand the solutions deeply enough that they can solve similar problems on quizzes and exams—leading to increased confidence in their math ability, which is critical to students' success in math.

Students also find help in a large, specially designed computer lab called the Math Technology Learning Center (MTLC). In two computer-lab sessions each week, the instructor, graduate teaching assistants, and peer tutors are available to help. In addition to the computers, which are arranged in circular pods of six to allow for student collaboration, the MTLC also has an area with tables and white boards for informal lectures and help sessions.

Besides attending the weekly lecture and completing the online homework, the students are required to come to the MTLC for a weekly online quiz based on the homework problems. They also take four exams and a comprehensive final exam there. Students who have a grade of 80 percent or above on homework, tests, and quizzes do not have to attend the otherwise-required twice-weekly MTLC lab sessions. But most choose to attend them anyway, because the lab is a very supportive environment in which they can get help with their homework and have their questions answered.

The redesign has significantly changed the role of the instructors and teaching assistants in the course. They used to spend their time lecturing, writing assignments and exams, and grading. Now they focus on guiding students through the course via the weekly meeting in a lecture room and then working individually with students in the learning center. The greater emphasis on individual instruction and one-on-one interactions with students is a change that most instructors find very rewarding.

Principles Contributing to Student Success

The success of the redesign appears to be attributable to a number of factors: Some are obvious, but several are not. We learned their importance the painful way, through trial and error. We present them here in the hope that they will guide others who are struggling to help students in courses with low success rates.

Principle 1: Provide a structure for the course that guides students in their active learning.

Most instructors are accustomed to a lecture format in which they explain the course content, hoping that the students are listening and learning. When students have an interest in the content, they probably do listen and try to learn. But in his article in the September/October 2007 *Change*, Carl Wieman provides compelling evidence that most students, and indeed most faculty, retain little information that is presented in a lecture format. He explains that this is not the fault of the learner but rather an inherent biological limitation in the amount of information that can be stored and retrieved from short-term memory. People learn best by discovering answers for themselves, which usually does not happen in a lecture course.

In the redesign of college algebra, we decided to abandon the traditional lecture in math and use the one "lecture" session each week to guide and direct students in their learning. This is when instructors present major points, answer questions, or provide a review for an upcoming test. Using the online course-management program, at the end of each week they post lecture outlines, a worksheet, and the tasks for the next week. They also post the homework for the coming week. Since many of the students have already worked on the homework before they come to the class, they are better prepared to ask questions.

In short, the students bear the responsibility for learning. The instructors are there to provide structure and guidance to help them learn. The lecture session provides an anchor and structure for the course that helps the students focus on the tasks they need to complete that week.

Principle 2: Provide sufficient time on task and enforce deadlines.

There is some tendency to confuse technology-enhanced learning—such as online tutorials, homework, and quizzes—with online courses in which students proceed at their own pace, completing a course within a specified period of time. The latter type of course works best for mature, motivated, and interested students—not the population we are discussing here. Less interested and motivated students require strict scheduling to be successful in courses they do not want to take.

We provide this by taking advantage of the technology to open and close student access to assignments, quizzes, and exams. While the tutorials and problems are available even after an assignment is closed, so that students who get behind can catch up, they lose points if they do not complete an assignment on time. This rigidity is what most students need to be successful in courses in which they typically procrastinate. Even the worst procrastinators learn fairly quickly that assignments must be done on time in order to get credit and make progress in the course.

One semester an instructor allowed the students to convince her to reopen a homework assignment that had been closed. Rather than helping the students, it seemed to hurt them. After that, many students failed to complete their homework on time, presumably because they thought they would get another chance. It took several weeks of enforcing deadlines before they were again completing the homework on time. Similarly,

Students collaborate in the MTLC at the University of Missouri–St. Louis.

when a new instructor complains that the homework system is not working, it is generally because deadlines are not enforced.

Principle 3: Reward students for their efforts.

The online homework assignments provide an easy mechanism to help students learn math by working several examples of the same problem. Students who are allowed to retry a homework problem as many times as they want often work until they get the correct answer, and they are rewarded for their efforts by achieving higher scores. The homework score is one-eighth of their final grade, and it is entirely under their control.

This gives students a clear message that they have the power to improve their grades simply by working harder. The weekly quizzes have the same types of problems as the homework, so those who have practiced the problems to increase their homework scores also score better on the quizzes. And students who spend the time to do that actually understand the concepts, know how to work the problems, and therefore do well on the exams. This explains the high success rate for students in the redesigned course.

> **The redesigned course, with its emphasis on online homework and collaborative learning ..., promotes active learning and provides students with individual assistance.**

Principle 4: Provide regular assessment of progress.

The online homework and quizzes with online grading provide students with immediate feedback, the opportunity to correct their homework mistakes, and ongoing assessment of their success in the course. The online grade book allows them to view their progress anytime, anywhere, so they always know how well they are doing. With this information, students know when they need help and where to find it.

Principle 5: Accommodate diverse styles of learning.

Students seek and benefit from assistance of various kinds. Some prefer to work independently and are very comfortable finding their help online, especially using the tutorials and guided solutions to math problems that are available with the software. These students rarely come to the lab except to take the weekly quiz, and many succeed very well using this approach.

Most of the students, however, benefit from the resources provided in the learning center, where the instructor and several teaching assistants are available to provide individual assistance with difficult concepts and with assigned homework. The circular computer clusters provide them the opportunity to collaborate, teaching each other and solving problems together. The area with tables and white-boards also allows for small-group lectures and discussions. The flexibility in design and the multiple sources of help that are available encourage students to come to the learning center and to stay until they have learned the material and passed the weekly quiz. The availability of help is especially critical to the success of students who are not comfortable with the subject.

Principle 6: Stay in touch.

Even with structure, strict schedules, rewards, assessment of their progress, and help in various forms, some students fall behind. Many who are not interested or motivated would like to be anonymous, but the technology makes their progress easy to track. The online grade book with an e-mail link to each student enables the instructor to see when someone has missed an assignment and to send a quick message offering help and reminding the student that the assignments must be completed on time.

It is very important for the instructor to begin this intervention early and to maintain contact with reluctant students. Once such students get off track, it can be very difficult to get them back on. The personal attention of the instructor often provides all the motivation a student needs to complete the assignments.

Additional Benefits of the Redesign

The redesign of college algebra has helped not only students but also the many faculty members teaching multiple sections of the course. In the redesigned course, all sections follow the same schedule, using the same homework assignments, quizzes, and exams. This section-to-section and year-to-year consistency is an important benefit. Evening sections are often taught by part-time faculty who previously received little guidance. Now, the detailed course plan ensures that new faculty understand not only the course structure but how to use the principles that have been developed as part of the redesign.

The redesigned course, with its emphasis on online homework and collaborative learning in the MTLC, promotes active learning and provides students with individual assistance. Students spend more time doing math and less time listening passively to lectures. Those who help their classmates in the MTLC learn the math better as they explain it to others. This type of opportunity for student learning did not exist in the traditional course.

Applying These Principles Across the Curriculum

In the redesign, through trial and error, we rediscovered some of the "Principles for Good Practice in Undergraduate Education" that were first described by Arthur Chickering and Zelda Gamson, including an emphasis on active learning, time on task, prompt feedback, and respect for diverse types of learning. But we also took advantage of some discipline-specific tools such as the algorithms that allow multiple examples of the same type of math problem.

Many of the principles we've described here, though, are applicable across disciplines, with some modification. Lectures are overused at the expense of active learning throughout the curriculum. In courses with a strong emphasis on factual content, students may need more lecture time than in mathematics. But in any course, learning can be enhanced by increasing the time that students spend actively learning.

In smaller classes, this can include small-group discussions and presentations interspersed with short lectures. In larger classes, personal-response systems, or "clickers," can keep students engaged and participating in the lectures (See "7 Things You Should Know About Clickers" at http://www.educause.edu/ir/library/pdf/ELI7002.pdf). Giving points for these exercises within a lecture setting increases student participation and learning.

The need for a defined course structure with clear expectations for students extends to virtually all undergraduate courses. Many students, especially those from underrepresented groups, are overwhelmed by the amount of work expected of them in college courses, particularly during their first year on campus. A syllabus that provides a schedule and clearly outlines expectations can help students plan their time. The less structure, the more likely students are to procrastinate, attempting to learn too much in too short a time. This cramming results in information that is stored only in short-term memory and does not contribute to deep learning.

Homework assignments with firm deadlines can especially enhance student success. Even if online homework and computer grading are not available, students can turn in assignments as electronic files and be awarded a modest number of points for doing the work, even if no grade is assigned. This encourages them to read the material and stay on schedule.

Assignments with deadlines and points not only keep students working but also provide instructors with information about individuals' progress. Online course-management tools such as Blackboard and WebCT allow instructors to monitor that progress and to send short e-mail messages to students who are falling behind, reminding them that help is available. Communication by e-mail and instant messenger is not only normal for most students, it is perceived as personal. Small gestures, such as using a student's name in an e-mail, can further the sense of connection and motivate students who feel invisible. Technology thus can increase faculty contact with students, personalizing interactions in ways that were not practical in the past.

Making Change Work

The redesign of college algebra was not easy, despite all the help of the Roadmap to Redesign Program. It required two years of hard work as well as considerable resources, the greatest of which was the time and effort expended by the faculty who designed, tested, redesigned, and retested the course. We struggled with recalcitrant software, reluctant colleagues who were comfortable with their teaching methods, and frustrated students who opposed change. Initially, we did not have the learning center and had to make do with computer classrooms that were not designed for individual help and collaborative learning. However, even with all the frustrations during the pilot testing, we saw improvements in students' learning and better attitudes toward math. This motivated us to continue and to see these improvements increase over time.

The redesign of college algebra also cost money. In many colleges and universities, instructors in lower-level courses have heavy teaching loads, and they must be provided with release time to make major changes. So funding was needed to reduce the teaching loads of the faculty who were redesigning the course, and the learning center required an investment of approximately $350,000. However, the redesign allowed us to increase class size, which decreased instructional costs over the longer term.

It is easier to identify the dollars that went into the redesign than to even begin to estimate the cost savings from increased student success. Success that leads to more science and engineering graduates cannot be measured in dollars. Ironically, one of the prices we did pay for the success of our students has been a decline in overall enrollment in college algebra, attributable to the fact that many students now take the course only once. This is a loss of income that we welcome.

Others who are interested in redesigning courses with low rates of student success should keep in mind these additional important points:

- Maintain flexibility, make incremental changes, remember that slow progress is better than no progress, and keep both a sense of perspective and a sense of humor.
- Instructors are often very resistant to change. They like the way they teach and are skeptical of technology. Be respectful but insistent that technology, used appropriately, not only enhances student learning but also frees faculty time to work individually with students, which is very rewarding.
- Instructors will not respond well to change unless you provide them with adequate training. They need help to understand the principles underlying the redesign and the techniques for implementing those principles. They also need technology training.
- Students also are often resistant to change. Although they may be very comfortable using technology in many aspects of their lives, many of them do not want to use it as a major tool for learning. Students are accustomed to a passive role in their learning and often object when the responsibility is placed on their shoulders. Again, as with faculty, one should be respectful but insistent that they learn best when they are actively engaged in the process of learning, particularly since personal help is available.

The types of fundamental changes we've described require commitments from many levels—from the administrators who allocate resources, to the department chairs who must support the instructors redesigning the course, to the instructors themselves as they devote their time and effort to the redesign. It is important to secure commitments from all those levels before initiating the process for change. But the demonstrable results very quickly justify an institution's having done so. C

Resource

■ Twigg, Carol A. (2005). *Course Redesign Improves Learning and Reduces Cost.* The National Center for Public Policy and Higher Education.