Enhancing Student Learning in Math Classes
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Project Summary
With support from NIH, Professor Gavosto develops and implements enhanced math classes in order to assist students with weak mathematical backgrounds, and she discovers that students in these classes excelled in this class structure above and beyond students in the traditional math courses, suggesting that all students might benefit from this type of instruction.

Background

The development of the enhanced math classes at the University of Kansas began in 2001 as a part of the Initiatives for Minority Student Development (IMSD) Project, which was funded by the National Institutes of Health (PI: Jim Orr, KU Department of Molecular Biosciences). The overall goal of the IMSD was to increase the number of under-represented minorities who enter careers in biomedical research, which has been a worrisome trend for decades. Recent surveys indicate that the percentage of students in underrepresented groups who take advanced math courses in high school, which prepare them to study biomedical disciplines in college and beyond, is much lower than for other groups, thus indicating that in order to improve the participation of under-representation of minorities in biomedical careers, there is a need to address the preparation of students in introductory math coursers. (See recent national report: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2007467). In an attempt to increase the number of underrepresented students who succeed in completing math requirements at KU, Professor Gavosto worked with the Offices for Diversity in Science Training: (http://www2.ku.edu/~odst/) to develop enhanced math curricula in the mathematics department. Other efforts to enhance performance in biology and chemistry introductory classes are also supported by IMSD.

Intermediate Algebra (Math 002), College Algebra (Math 101), and Calculus I (Math 115) are prerequisites for students to complete the math requirement. The KU math requirement consists of completing a course beyond college algebra, for example Calculus I, Math 115. Math 115 is a coordinated course, taught mainly in small classes of 30-35 students with common gateway, midterm, and final exams. Students who have a math ACT of 26 or equivalent, or those who have taken College Algebra, may enroll in the course. If students do not meet the prerequisites for Calculus I, they are required to take one course, College Algebra (Math ACT 22-25), or two courses, Intermediate Algebra (Math ACT below 22) first and then Math 101. The College Algebra and Intermediate Algebra courses have smaller average classes sizes than Calculus I, with 20-24 students per section.

Several types of assistance are provided to students enrolled in any of these three courses. Calculus I has a consulting room offering free tutoring, with tutors available for more than 35 hours per week. Likewise, students in Intermediate or College Algebra take part in the Kansas Algebra Program (http://www.math.ku.edu/academics/kap/), which has a help room offering free tutoring for more than 60 hours per week, skill tests, videos of classes, un-timed exams and re-take exams in a testing room. Although the program is successful, many students who could

benefit from the additional support provided from the Kansas Algebra Program do not take advantage of the help available.

Implementation

When developing a program out of the IMSD project, the first attempt at increasing the likelihood of students' taking advantage of additional assistance included the provision of individualized tutoring to underrepresented students. However, individualized tutoring did not work very well, because students still did not fully take advantage of this service, coupled with the fact that it was also difficult to identify students who needed extra assistance.

For a second attempt, Professor Gavosto drew on observations that students seemed to be more engaged with course material if the class met every day, as opposed to meeting two or three days a week. Thus, the revision to the enhanced math sections included the addition of two extra class periods to the course structure, such that these courses would meet every day for a class period of 50 minutes. These additional class periods mirrored the approach of programs at other universities, where students take the same calculus course but with extra class periods to compensate for a weak background in calculus. Moreover, the additional time periods would be used in the spirit of a Treisman seminar. The Treisman seminars are based on Uri Treisman's work with African-American students at Berkeley in the 1980s. His approach was to replace the remedial work that these students were participating in with honors-level work; this level of work encouraged students to collaborate on challenging problems in an environment of high expectations. His method has been adopted in many programs with great success. (Check here for more information on the Treisman method: http://math.sfsu.edu/hsu/workshops/resources.html). During these additional class meetings, students would be able to strengthen their background through "enhanced" work, not "remedial" work. For a breakdown of how the enhanced sections' daily work compared to the regular sections' daily work, see math_115_compare_class_schedule.doc. Furthermore, the class size was restricted to 20 students, compared to the normal class size of 20-35 students in each section. This was a particularly significant decrease in class size for the Calculus I course.

The requirements for students to enroll in the enhanced math classes were first year students of any ethnicity who:

1. Had a relatively weak background or apprehension about mathematics, and
2. Expressed a desire to improve their math skills.

What did the extra time provide to students enrolled in the enhanced sections?

- A more comfortable and enjoyable learning environment
- Increased opportunities to interact with the teacher and other students in the class, through:
    - Individualized help and mentoring
    - Group work and peer learning
- A deeper grasp of the course content, through:
    - More detailed explanations of concepts and related background
    - More complicated problems, multiple approaches and solutions to problem solving
    - Extended use of the technology and detailed training on the use of the graphing calculator

- Study skills, time management, and college and career planning advice

For the enhanced sections, instructors were carefully selected. The instructors, who were primarily GTAs, were chosen based on teaching experience both in the classroom and in the type of environments where they had previously taught. Instructors who had previous experiences with students from a diverse background were preferred. We also looked for instructors with experience at KU who had knowledge of our program and the university in general.

For a discussion of our approach as described in CTE's Teaching Handbook, see gavosto_quantitative_classes.doc.

Instructor comments on implementation

Several instructors have provided comments on the implementation of the enhanced math sections:

Amy Kim (taught Calculus I during the Spring 2005 and Fall 2005 semesters):
"I have taught both the regular and enhanced sections. In the enhanced sections, I always try to help students develop good organization skills and study habits. I expect students to keep notes and homework well organized. In addition, during the first week of classes I have students map out a typical week of classes, work and extra curricular activities to help them find times to study mathematics, as well as their other subjects. Students feel like they have more control over time if they manage it appropriately, and they don't feel so overwhelmed in college.

Cooperative learning and group work is a big part in the enhanced math sections. Students become more engaged with the topics if the atmosphere in the classroom varies. This way, when students are home completing assignments, they may be able to reflect back on the group discussions and answer their own questions. In addition to group work, the graphing calculator is an awesome tool to enhance the learning process. Once students have a firm grasp on the material in a particular section, it is always great to allow them to explore these problems graphically and numerically.

One motto I follow for the class is "Practice make perfect." If students can work up to the challenging problems in the textbook, then they have confidence and can tackle any problem they are given with the tools they have created for themselves."

Benjamin Pera (taught Intermediate Algebra during Fall 2006):
"The enhanced sections offered students more time for in-class practice of homework, more time for questions, substantially smaller class sizes with more one-on-one help, and more time for examples than a regular section. In addition, the overall pace through the material was at a slower rate than the regular sections, which allowed students to absorb more information. The extra time also allowed me to have more group study time, where students worked on homework and projects in groups and pairs. This helped them build confidence in themselves, in each other, and helped them develop their teamwork skills."

Student Performance

There are several indicators that suggest that these enhanced sections were beneficial. These indicators include students' performance across the course, student performance on the final essay exams and samples of students' work, drop-out rates, course evaluations, and instructor comments. Each of these measures is outlined below.

1. Students' performance: Course grades
In comparisons of overall performance between students in the enhanced sections to students in the traditional sections of the courses, students in the enhanced sections performed at a level that was at least one letter grade higher than their peers in the traditional course. This is a similar pattern to what other institutions are finding when they implement an enhanced math class format. For example, UT Austin's Emerging Scholar Program in Calculus found that students in the enhanced sections of calculus were on average obtaining a B+ in their first semester of calculus, which is a 0.5 grade point average better than their peers in traditional classes. Furthermore, in their second semester of calculus, the emerging scholar students are obtaining an A average, which is 0.75 grade points better than the average in the regular second semester calculus classes. Similarly, Wisconsin's Emerging Scholars Calculus program found that in students' first two semesters of calculus, the students in the enhanced classes are performing half a grade point higher than students in the regular sections, and this is when pre-college math abilities are statistically controlled for. Thus, it appears that this type of enhanced program is significantly increasing students' level of mathematical understanding. Students also report taking pride in their work they did. For some students, this is the first math course for which they have ever earned an A. Often the grade that they earn in the enhanced math class is the highest grade that they have ever earned in a math course.

2. Students' performance: Student work
Students in Math 115 (both the enhanced and traditional sections) took the same final exam over the course material. This provided an equal base of comparison across the two types of classes. First, an examination of the overall exam performances between the enhanced Math 115 course and two traditional Math 115 classes was conducted. While the traditional classes scored an average of 68% (median = 67%) and 74% (median = 75%) on the final exit exam, the enhanced Math 115 class scored an average grade of 83% (median = 85%), indicating increased understanding in the enhanced class.

A follow-up analysis addressed whether there was a particular type of question on which the enhanced section excelled. To answer this, each question on the Fall 2007 final exam was categorized in terms of the type of skills and understanding that it required, using Bloom's taxonomy. (link to new web page: Bloom's taxonomy) This table (see final_exam_bloom_table.pdf) indicates the raw number and overall percentage of questions from each chapter that were included on the final exam. As can be observed in this chart, the exam mostly emphasized knowledge and comprehension questions, with the fewest number of questions asking students to engage in application.

After the classification of the exam questions, the percent of each type of question answered correctly was then examined for each class section. A bar graph of this information is presented in correct_responses_final_exam07.pdf. As evidenced by this data, the enhanced Math 115 section outperformed the traditional Math 115 classes on each type of question. However, all

students, including those in the enhanced class section, performed more poorly on the application-directed questions than on the knowledge/comprehension- or the analysis-directed questions.

In an attempt to determine why lower levels of performance were observed when students were asked to apply the course material, the type of preparation and practice that students in the enhanced-classes were asked to engage in across the semester was assessed. In terms of class work, the amount of time spent in each class on knowledge/comprehension, application, and analysis material was examined; a break-down of the daily material, in terms of Bloom's taxonomy, covered in the enhanced-sections is provided in time_breakdown_bloom07.pdf, and a condensed table of the amount of time spent lecturing on material related to the three Bloom's taxonomy categories is provided in time_lecture_bloom07.pdf. Since the time spent in each chapter varies, overall percentage averages were calculated as well: 43% of the total lectures covered topics and examples in the knowledge and comprehension categories, 22% were focused on application problems and examples, and 35% of all lectures discussed and examined analysis questions and examples.

The percent of homework and group work problems completed by students in each taxonomic category was examined, as well (see homework_groupwork_bloom07.pdf). Since the time spent and number of problems assigned per chapter varied, overall percentage averages were also calculated: 52% of the problems assigned to the students covered topics in the knowledge and comprehension categories, 18% were focused on application problems and 30% of all the assignments were analysis questions. This bar graph (see percent_bloom_class_assigned work.pdf) illustrates the relative percentages of each category of material, comparing the lecture topics to the problems assigned. Based on the amount of time spent in the analysis category inside and outside of the classroom, it was not surprising that the students did well in this category on the final exam. The more time focused on this category versus the application problems may have affected the results.

Two examples of analysis questions from the final are included here:

- Analysis Example 1: (analysis_example1.pdf) Once the student obtained the volume function, it appears that they graphically found the correct solution.
- Analysis Example 2: (analysis_example2.pdf) This student had no trouble analyzing the problem, creating a diagram, and properly labeling the variables.

Overall, the students seemed to struggle with the knowledge and comprehension questions, as well. They appeared to have a general understanding of the underlying ideas of calculus, but sometimes they lost track of the details in their computation. The document analysis_example3.pdf provides a student's response to a comprehension question where the student did not use the correct rule of differentiation. Another example is provided in analysis_example4.pdf), where a student does not initially apply the properties of logarithms, which simplified the question being asked.

In an attempt to address students' relative weakness in the area of application according to Bloom's taxonomy, the focus of the course itself was shifted, with more time spent in and out of class on application-related understanding. As can be seen in these bar graphs (see

worked_problems0708.pdf), more time was spent both in-class and out-of-class on the working of application problems in the Spring 2008 semester than in Fall 2007. There was also a slight increase in the number of application-type questions (see questions_final0708.pdf) asked on the Spring 2008 Final Exam relative to the Fall 2007 version.

To examine whether an increased emphasis on application questions affected student understanding, the final exams for the Spring 2008 courses were analyzed (see correct_responses_final_exam08.pdf). Although students in the enhanced math sections answered more questions correctly than students in the traditional math sections overall, what is most interesting is the increase in application-type question performance (see compare_correct_responses_final0708.pdf). While students in the Fall 2007 enhanced sections exhibited a U-shaped function, with the lowest levels of understanding demonstrated on application-based questions, the Spring 2008 enhanced math section students exhibit a much more linear and steady understanding across the three components. Therefore, it is apparent that when an increased focus is applied to an aspect of student understanding, that learning can be bolstered.

3. Pre- and post-test assessments of mathematics accessibility and utility
Students in the enhanced and traditional Math 101 and Math 115 classes were asked how closely the following statements matched themselves, at the beginning and at the end of the semester:

1. Mathematics is enjoyable and stimulating to me.
2. Communicating with other students helps me have a better attitude towards mathematics.
3. The skills I learn in this class will help in other classes for my major.

The results were as follows:

		Math 101e	Math 101	Math 115e	Math 115
Q1	Beg	1.93	2.65	2.71	3.27
	End	2.40	2.55	2.90	3.50
Q2	Beg	3.23	3.16	3.64	3.39
	End	3.50	3.72	3.80	3.68
Q3	Beg	3.38	2.89	4.07	3.91
	End	3.50	2.90	4.30	3.53

These results indicate that initially students in the enhanced sections of each class considered math to be less enjoyable and stimulating than did their peers in the traditional sections. However, at the end of the semester, students in the 101 class ranked math as enjoyable as did students in the traditional class. Across the board, there does not appear to be much difference in how helpful students viewed communication with their peers. Finally, in terms of the long-term application of the skills that they learned in their math class, there were modest improvements for students in both enhanced classes across the semester, but the class invoked no difference in evaluation of utility by the traditional Math 101 students, and the Math 115 students actually viewed their mathematical training as being less helpful for future classes as the semester wore on. Therefore, there seem to be some positive trends in the students in the enhanced classes in particular, especially in the areas of how enjoyable they find the subject and how useful they think that their current knowledge base will be for future courses. As one of the goals of this initiative was to increase interest in pursuing careers in which mathematical skills will be

required, the observed increases in student engagement with math suggests that they may be more likely to continue in a math-related field as compared to their peers who view their math knowledge as having less future utility.

4. Drop rates
Another indication of student success with the enhanced math classes is the decrease in the number of students who dropped the courses, compared to the traditional courses. In particular, the drop rate for those enrolled in Intermediate Algebra was noticeably lower than the overall drop rate for that course, and the drop rate in Math 115 has been significantly lower in the past three years, since the enhanced math classes have been implemented.

Course evaluations
In terms of course evaluations, we also see that students are positively responding to the enhanced math classes. In particular, the average C&I score for item #8 *("Overall, (s)he is an effective teacher"*) for the instructors teaching the enhanced courses since the 2002 Fall Semester are (out of 5 points):

Intermediate Algebra: 4.73
College Algebra: 4.74
Calculus I: 4.94

These numbers were significantly higher than the average response for the instructors in the regular sections during the same period.

Instructor observations on student performance
Finally, the instructors have also noticed significant improvement in their students. For example, Amy Kim reports, *"The enhanced math program has been very successful for students. In the Fall 2005 semester, no one received less than a B on the Math 115 midterm and the enhanced section earned the highest midterm and final grades across all sections. In addition, all of the enhanced Math 115 students passed the gateway exam on the second day of the testing period."*

II. Reflections

Overall, the enhanced math sections have been very successful. The extra dedication and resources allocated to these sections produced many positive outcomes, such as improved performance, more students completing their math courses, and higher evaluations of the course instructors. Combining appropriate learning environments, dedicated teachers, and committed students brought about these successes; this combination yielded excellent results.

The instructors of the enhanced math classes have also expressed that their courses were successful. For example, Brian Lindaman says, " Teaching the enhanced section was really fulfilling—the students were motivated, [and] having class every day allowed me more flexibility in deciding how much content to present in any one day. The extra time also allowed me to help students review more for tests." Another instructor, Benjamin Pera, stated, "One of the students said that [they] finally knew what it takes to do well in a math class. I think that is the biggest payoff for the students in the enhanced class—the keys to succeeding in math, and academia for that matter. I think it enables them to really envision themselves as strong students, because they know what kind of standards they need to be willing to set for themselves in order to get there."

Therefore, it appears that the Treisman approach is beneficial. In particular, it may be most beneficial to students when they are making a transition in understanding and expectations. These difficult transitions of knowledge can occur when students shift from K-12 to a university, when students transfer from two-year to four-year universities, or when students are shifting from courses that focus on computational skills to theoretical understandings. (For a discussion of examining student transitions in understanding, see baxter_magolda2004.pdf).

The IMSD grant has been renewed by NIH twice. In the proposal reviews, there have been favorable reports and evaluations of the curriculum enhancements supported by the initiative. In addition, an external review of the IMSD program conducted by experts concluded that the preliminary data indicate that the enhanced mathematics courses are increasing student performance and recommended that the College of Liberal Arts and Sciences should increase the amount of institutional funds committed to supplemental instruction in biology, chemistry, and mathematics courses.

While these enhanced math sections have been successful, there are still some challenges for the future. First, it would be beneficial to better understand why the students do so well in these classes and to investigate how students could be prepared to do equally well without the extra support. Professor Gavosto is currently working with a graduate student on the development of a survey that will help determine how the experience in these sections changes students' study habits and attitudes towards mathematics courses, which may provide some insight into the types of changes that are being produced in these students.

Second, there is a financial challenge, such that the cost of the enhanced sections does not currently allow the extension of these courses to for all students. However, the aspects of learning that can be reproduced in other classes are becoming apparent, so that all students may benefit. So far, a few key points learned from the enhanced sections that could be used for training of GTAs in all the regular sections are:

- Finding ways to acknowledge all students enrolled, not just the ones who always come to class, and setting high expectations for all students.
- Giving regular feedback and actively following up with students who under-perform.
- Actively encouraging classroom attendance and participation.
- Describing and modeling good study habits in mathematics.
- Periodically reminding students of available resources and approaching deadlines, especially during the fall semester for first year students.

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