Improving Retention by Redesigning Freshmen Mathematics with the Dimensions of Learning Pedagogy, Assessment and Technology Framework

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Abstract

The retention of engineering students continues to be a major issue affecting engineering schools across the country and unsuccessful experiences in freshmen mathematics is one of the factors attributing to this problem. This paper presents a freshman mathematics course reform aimed at reducing Calculus I preparation time by at least one semester, improving pass rates and ultimately increasing the retention of engineering and computer science students. The Dimensions of Learning pedagogy, the use of technology and performance assessment are the main components of the framework used. A wireless mobile classroom was the key technological feature used in the redesign. The innovative Pre-Calculus course (IPC) redesign was performed by a multidisciplinary team of faculty from the Schools of Engineering, Science and Education. The project design, implementation aspects, assessment techniques and evaluation results are given. The first course offering shows a 14% higher pass rate ('C' or better) in the innovative pilot course than that of the sections taught in a traditional format. Moreover, 81% of the new freshmen enrolled in the IPC and who placed in a mathematics course one or two levels below the IPC, via the University's placement test, received a 'C' or better. Assessment results of the frameworks used will be given as well. Preliminary results indicate that this comprehensive approach can be a viable format for optimizing teaching and learning, and thereby improving student retention and academic success.

Introduction

Many students are not Calculus ready upon entering colleges and universities and they also are unsuccessful at negotiating Calculus I at the first attempt, both which affects time to degree completion and impacts the students desire to remain in engineering, thereby affecting retention. In addition, when students initially take engineering courses, they often have difficulty translating mathematical concepts and knowledge to solve engineering problems. A Calculus Preparatory course has been redesigned by a multidisciplinary team of faculty from the Schools of Engineering, Science and Education in order to increase the retention and academic success of engineering and computer science students. This course is being developed with the intent of engineering and computer science students, with varying mathematics preparation, completing Calculus I by the end of the first year, at a maximum. The objectives of this redesign are to 1) understand the learning process; 2) develop faculty who model best practices in integrating teaching and instructional technology; 3) increase the short and long term retention of electrical

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engineering and computer science students; and 4) increase students' ability to apply mathematics to engineering and scientific problems.

The innovative course unit redesign is comprehensive in pedagogy, assessment and resource support, including the integration of technology and learning. The pedagogy that is used is based on the Dimensions of Learning (DOL) framework, a powerful, effective and comprehensive model that uses what researchers and theorists know about learning to define the learning process. It differs from most pedagogical approaches used in higher education, and with this technique the optimum approach to teaching and learning is being sought. Engineering applications are being incorporated to motivate students and enhance their learning.

Typically only 25% of new freshmen engineering students at Morgan State University enroll in Calculus I (MATH241), based on the University's mathematics placement test, leaving 75% who are not "Calculus ready." The average success rate ('C' or better) in Calculus I is 49.5%. Based on these statistics and our awareness of the difficulty students have in negotiating their first math courses, it is clear that mathematics has a profound impact on student success. Although Calculus I is the first math course required of engineering students, since 75% of our new freshmen begin in a math course other than Calculus I, (Basic Algebra, Pre-Calculus I, or Comprehensive Pre-Calculus), based on the University's mathematics placement test, a much stronger affect on retention could be obtained if the Calculus Preparatory courses were impacted as well as Calculus I. Depending on students' mathematics course placement, it could take one to four semesters to complete Calculus I. Using an integrated and comprehensive approach with novel pedagogy, assessment, and technology, and other strategies, an innovative Pre-Calculus course (IPC) has been designed and offered for the first time in Fall 2003.

Dimensions of Learning (DOL) Pedagogy

A major component of the course reform is the pedagogy used which is based on the Dimensions of Learning (DOL) framework. Its premise is that five types of thinking, or five "dimensions of learning," are essential to successful learning. Robert Marzano of the Mid-continent Research for Education and Learning (McREL) Institute developed the Dimensions of Learning Framework in 1997. The framework grew out of many years of research into how we learn most effectively, and is designed to translate research into a practical classroom application to improve teaching and learning in any content area [1]. It ensures that instruction takes into account all five of the critical components of learning which include 1) Positive Attitudes and Perceptions about Learning; 2) Thinking Involved in Acquiring and Integrating Knowledge; 3) Thinking Involved in Extending and Refining Knowledge; 4) Thinking Involved in Using Knowledge Meaningfully; and 5) Productive Habits of the Mind. Implicit in the Dimensions of Learning model are six basic assumptions: Instruction must reflect the best of what we know about how learning occurs.

- Learning involves a complex system of interactive processes that includes five types of thinking—the five dimensions of learning.
- What we know about learning indicates that instruction focusing on large, interdisciplinary curricular themes is the most effective way to promote learning.
- The curriculum should include explicit teaching of higher-level attitudes and perceptions and mental habits that facilitate learning.
- A comprehensive approach to instruction includes at least two distinct types of instruction: one that is more teacher-directed and another that is more student-directed.

- Assessment should focus on students' use of knowledge and complex reasoning rather than on their recall of low-level information.

The Dimensions of Learning (DOL) framework is different from the traditional approach to teaching in that all five dimensions of learning are addressed in unison. Most traditional approaches to teaching tend to focus on one or two of the aforementioned dimensions. The goal is to develop a learner with the knowledge, skills, and dispositions to succeed as a student and as a professional. The framework has been adopted by educators and researchers in several countries including Japan, Germany, South America and Canada. It is popular because it can have an impact on virtually every aspect of education and can be used as a resource for instructional strategies, a framework for planning staff development, a structure for planning curriculum, and performance assessment such as reflection logs, portfolio, performance tasks, and rubrics, features that may not be included in traditional teaching approaches[2].

Attitudes and perceptions affect students' abilities to learn. DOL 1 indicates that a key element of effective instruction is helping students to establish positive attitudes and perceptions about the classroom and about learning. Helping students acquire and integrate new knowledge is another important aspect of learning. According to DOL 2, when students are learning new information, they must be guided in relating the new knowledge to what they already know, organizing that information, and then making it part of their long-term memory. When students are acquiring new skills and processes, they must learn a model or set of steps, then shape the skill or process to make it efficient and effective for them, and finally, internalize or practice the skill or process so they can perform it easily. Once knowledge is acquired, it can then be extended and refined, according to Dimension of Learning 3 (DOL 3), by applying reasoning processes. Dimension 4 uses knowledge to perform meaningful tasks, which is what engineers do. This is one of the most important parts of planning a unit of instruction. The problem solving, inquiry and system analysis associated with this dimension is well suited for engineering and scientific applications. Dimension 5 indicates that most effective learners have developed powerful habits of mind that enable them to think critically, think creatively, and regulate their behavior. The five dimensions work together to ensure that students acquire conceptual understanding of their subject matter. All of these dimensions are important in the learning process, and by using all of the five dimensions of learning in the course redesign, it illustrates that the optimum approach for teaching and learning is being sought. Table 1 summarizes the advantages of the Dimension of Learning approach over the traditional teaching pedagogy. DOL is comprehensive, integrated and connected while the traditional mode of teaching is separated.

Table 1 Traditional versus DOL (Mastery Learning)

Traditional		**Dimensions of Learning (DOL)**	
Separated	Lecture	**Comprehensive, Integrated, Connected**	Contextual Learning, Reciprocal Teaching & Lecture
	Technology		Technology-mobile, instantaneous feedback
	Tests		Performance Assessment
		Coherence-instruction, technology, performance assessment *all tied together*	

Approach to Course Redesign

In order to meet the objectives of the redesign and use the integrated, comprehensive approach, a systematic process was implemented. Education in the Dimensions of Learning pedagogy and the Discourse interactive software, a review of mathematics standards, lesson plan development and assessment instruments development are some of the activities that were performed. The declarative knowledge (what you want students to know) and the procedural knowledge (what you want students to be able to do) were determined. This involved examining mathematics and engineering standards or outcomes based on accrediting and oversight boards[3]. This declarative and procedural knowledge represent the course learning outcomes. The mathematics faculty selected appropriate classroom DOL strategies to address classroom climate as well as the other aspects of the Dimensions of Learning. DOL allows faculty to use higher-order thinking skills. The instructor developed lesson plans for all of the course units and incorporated the Dimensions of Learning in each topical concept. The instructor had to carefully think about strategies for each concept in the course. Lesson plan development incorporates best practices for teaching and learning in engineering and education. The education faculty developed the assessment instruments and was the expert on the Dimensions of Learning pedagogy and the engineering faculty was responsible for the project oversight, the technology integration and engineering applications. Because this approach is so integrated, the "team" concept was imperative for this project.

Course Implementation and the Wireless Mobile Classroom

For the Fall 2003 semester, two sections of the course were offered sequentially with an enrollment of twenty-eight and twenty-seven students in sections 201 and 202, respectively, for a total of fifty-five students. Fifty-two students remained in the course for the duration of the semester.

The course began with a one-week orientation. Dimension 1 of the DOL pedagogy is Positive Attitudes and Perceptions about Learning. Research indicates that attitudes and perceptions related to the teacher, other students, one's own abilities and the value of the assigned tasks influence learning. When attitudes and perceptions are positive, learning is enhanced. When attitudes and perceptions are negative, learning suffers. In order for the other Dimensions to be effective, Dimension 1 must be effective. During the orientation, the project team members formally presented their roles to the class. The areas emphasized were to 1) orient students to project goals and expected outcomes; 2) help build a strong learning community; 3) understand course content and instructional framework; 4) understand the assessment framework; and 5) understand the impact of technology on experiences and attitudes.

The use of technology was a key aspect of the course redesign as well where the Wireless Mobile Classroom (WMC) was used. The MBC consists of thirty student notebook PCs, an instructor notebook, a LCD projector, a laser printer and accessory supplies. Training for the participants was essential and occurred during the orientation. Upon entering class the each student was provided a notebook computer that contained the Discourse software, which is an instructional delivery software which creates an interactive learning environment. For the instructor, Discourse provides immediate assessment, immediate observation of student progress and instructor control that allow for faster adjustments in order to impact student performance. The use of Discourse in the classroom provides a great alternative to traditional means of classroom assessment. Immediate feedback is available on in-class exercises, quizzes and exams. Technology is used in other ways as well. It is also used to surf the internet as a class.

All lectures are presented using PowerPoint with additional instruction given on the chalkboard. The instructor also uses textbook-based software to supplement classroom instruction with demonstrations and simulations that illustrate mathematical concepts and their applications to scientific and engineering problems.

It was impressed upon the participants that a "Community of Learners" environment was desired to be established. As a part of the course, students submitted weekly reflective journals. Students were to establish portfolios that contained downloaded class notes along with other documentation, in order to further enhance learning. Some students did this consistently, although more uniformity is desired.

Two in-class undergraduate facilitators and two tutors were assigned to the course. The planned role of the facilitators was to assist the faculty member in the classroom for maximum effective active and collaborative learning. The undergraduate facilitators primarily assisted with much of the technological aspects of the project. Since this was the first course offering, there were technical aspects that required attention early in the semester. These upperclassmen were an important part of the team and worked closely with the instructor.

Performance Assessment

Explicit measures of the project's impact on retention are the retention rates of the pilot group as compared to those students in the traditional courses. Success rates of students in the innovative Pre-Calculus for the Fall 2003 semester have been determined. The long-term success and retention of these students will be examined as they continue throughout their program of study. There are several factors that may contribute to this success. Students' attitudes and perceptions of learning and the learning environment, including motivation, confidence, and professional and technological competency, are key contributing factors to retention. Therefore, assessment of the impact on student learning was performed and tied to the DOL dimensions and five issues related to the topic of curriculum planning, instruction, and assessment. Surveys were given to students throughout the semester after each unit of the course and at the end of the semester. At the end of the course the participants also responded to open-ended questions. The project team met regularly during the semester and used the analyzed data for continuous course improvement.

Assessment techniques that were utilized in the course include technological competence and use, performance tasks, portfolios, reflective journals, teacher observation, and student self-assessment. Rubrics were developed and used for some exams. Rubrics or criteria for judgment promote learning by offering clear performance targets to students for agreed-upon standards. Table 2 provides the rubric that was used for Task B on one of the examinations. Note that by specifically indicating the elements used in evaluating a student's work and stating what constitutes the scoring leads to a more objective and consistent assessment for each student, and if used appropriately, can assist in students' performance by letting them know what is expected. A Task B declarative and procedural knowledge description and the exam are companions to the rubric.

Table 2 Sample Rubric for Task B

Scale	Element #1	Element #2	Element #3	Element #4
Points Earned (10 pts. TOTAL)	**Notation (2 pts.)**	**Mathematical Procedure (3 pts.)**	**Mathematical Logic (3 pts.)**	**Effort used in problem solving (2 pts.)**
3		All steps of mathematical procedure were correct in solving the problem	Logic was very clear and concise in problem solving	
2	Proper notation was used in all steps of solving the problem	Most steps of mathematical procedure were correct in solving the problem	Logic was clear and concise in problem solving	Considerable effort was used
1	Some correct and some incorrect use of notation in solving the problem	A few steps of mathematical procedure were correct in solving the problem	Logic was somewhat clear and concise in problem solving	Little effort was used
0	No correct use of notation in solving the problem	No steps of mathematical procedure were correct in solving the problem	Logic was not clear or concise in problem solving	No effort was used

Project Evaluation Results

Analysis of the results is done by examining the success rates in the innovative Pre-Calculus course as well as examining the framework utilized. Since one of the aims of the course redesign is to reduce the amount of time to become Calculus ready, this aspect is used in evaluating the project as well.

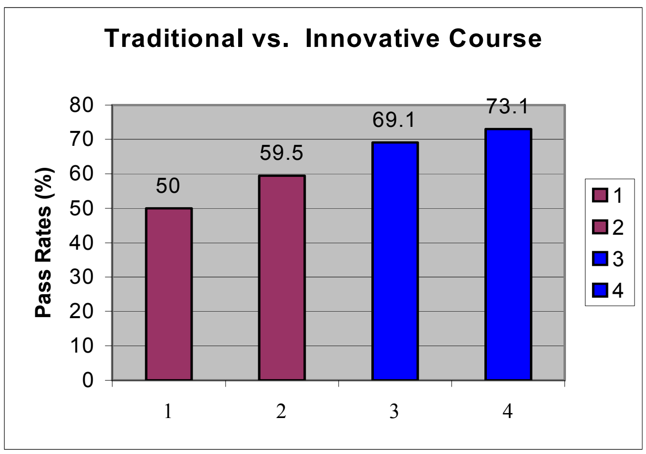
Quantitative Results using Pass Rates

The quantitative evaluation of the course was performed looking at two aspects: 1) the pass rates for students taking the Innovative Pre-Calculus Course; and 2) the framework using data on student achievement, instructional support structures, quality of instruction, learning environment, and student motivation.

The pass rates and the retention rates are the main evaluation criteria. The pass rates for students in the innovative Pre-Calculus course are compared to those enrolled in two sections of the traditional Comprehensive Pre-Calculus course for Fall 2003. In addition, the pass rates for students in the IPC who normally would have been placed in a course one or two levels below the pilot course are examined.

The University's policy is that students must enroll in the mathematics course for which they place. The innovative Pre-Calculus course is tailored for those students who either place in Pre-Calculus I, which is two levels below Calculus I, or the traditional Comprehensive Pre-Calculus course, which is one level below Calculus I. If the students who placed into Pre-Calculus I are able to complete the innovative Pre-Calculus course, it could reduce their time to graduation by one semester. Since "time to graduate" impacts retention, successful completion of the IPC by students who placed in Pre-Calculus I could have a tremendous impact on the success of engineering and computer science students. In addition, assessing the framework provides us with more detailed information in order to ensure continuous improvement. It gets closer to assessing the important Dimensions of Learning.

Let Cohort1 be the number of students who initially enrolled in a Pre-Calculus course and let Cohort2 be the number of students remaining after the add/drop period. For our assessment, both numbers will be considered because a “drop” means that students have to enroll in the course in a future semester, adding at least an additional semester to their program, which could impact retention. In Figure 1, the burgundy color represents the pass rate in the traditional course while the blue color indicates the pass rate in the innovative Pre-Calculus course. Figure 1 illustrates that 69.1% of the number of students who initially enrolled in the innovative Pre-Calculus course received a grade of ‘C’ or better versus 50% of the number of students who initially enrolled in the traditional Pre-Calculus course. If we only examine the students who remained in the course after the add/drop period, the pass rate for the innovative Pre-Calculus course is 13.6% higher than the traditional course. The comparison of the Fall semester groups show better results for the innovative course; however, these are preliminary due to the small sample size.



1=Cohort1 Traditional (50 students) 3=Cohort1 Innovative (55 students)
2=Cohort2 Traditional (42 students) 4=Cohort2 Innovative (52 students)

Figure 1 Pass Rate in Traditional vs Innovative Course

Students who initially placed into courses lower than the traditional Pre-Calculus course (Basic Algebra, Pre-Calculus I) benefited from the innovative Pre-Calculus course as well. Of the thirty-five new freshmen enrolled in the innovative Pre-Calculus course (IPC) for which we have placement tests results, sixteen of them placed into Pre-Calculus I and fourteen of the sixteen students (87.5%) received a ‘C’ or better in the pilot course. There were five students enrolled in the IPC who placed into Basic Algebra. Three of the five students (60%) passed with at least a ‘C.’ While these results may be due to several factors, it is anticipated that the integrated and comprehensive approach of the pilot course was influential on these positive outcomes.

Quantitative Results using the Framework

Data on student achievement, instructional support structures, quality of instruction, learning environment, and student motivation are the focus on this section of the evaluation.

Student achievement refers to the data on attendance, homework, quizzes, and exams. The Fall 2003 attendance rate was 81%. The total homework mean for the pre-calculus course was 75. The total quiz mean for the course was 70, and the total exam mean was 80. Eighty-percent (80%) of the students reported that the course increased their reasoning and thinking skills. In summary, the data on student attendance, homework, quizzes, and exams were positive.

Technology, course material and handouts, and the tutoring sessions were the main instructional support structures. The Discourse software, Tablet PC, Laptops, and Blackboard were the technological support structures. Eighty-five percent (85%) of the students reported that the technological resources helped them to learn and understand the pre-calculus tasks and assignments (in-class, homework, quizzes, and exams). Seventy-four percent (74%) of the students reported that the tutoring sessions contributed to their ability to complete the course projects and assignments. Seventy-seven percent (77%) of the students reported that the lecture activities, material and handouts contributed to their ability to complete the course projects and assignments.

Perception of the different aspects of instruction (lecture, group-work, discussions, etc.), perception of the instructor, and student-teacher relations are all indicators of quality of instruction. Eighty-four percent (84%) of the students reported that the instruction that they received was one of quality. Compared to other instructors seventy-five percent (75%) of the students reported that the instructor was among the best they ever had. Seventy percent (70%) of the students reported that they were satisfied with the instructor.

Learning environment is defined as the community of learners or the atmosphere created to enhance the quality of the relationship between students, mentors, and the instructor. Seventy percent (70%) of the students reported that, when they needed their help, their classmates helped them with their course projects and assignments. Ninety-two percent (92%) of the students reported that they had a positive relationship ("get along well") with their classmates. Eighty-percent (80%) of the students reported that they often help their classmates solve a problem once they figured it out. Sixty-five percent (65%) of the students reported that, when they needed their help, their mentors helped them with their projects and assignments. Seventy-four percent (74%) of the students felt that their mentors really listened to them. And, as mentioned in the previous section, seventy percent (70%) of the students reported that they were satisfied with the instructor.

Student motivation refers to their perception of the course tasks and assignments. Students rated the different aspects of the innovative Pre-Calculus course tasks and assignments positively. Sixty-two percent (62%) of the students reported that course tasks are interesting. Sixty-three percent (63%) of the students reported that course increased their confidence to take other calculus courses. Eighty-percent (80%) of the students reported that the course increased their reasoning and thinking skills, and seventy-three percent (73%) of the students reported that the course tasks and assignments were understandable.

It was also found that elements of the instructional framework are significantly related to student achievement and motivation for learning. Dimension 1 positive attitudes and perceptions for the pre-calculus tasks are significantly related to students achievement defined as exams and quiz scores. Results of the correlation analysis is Pearson's $R = .38$, $p < .05$ for exams; and $R = .50$, $p < .01$ for quizzes where the probability p provides the confidence level in the relatedness statements. For the preceding statements there is a 95% and 99% confidence level, respectively. Elements of the framework are significantly related to student problem solving skills. Dimensions 1 attitudes and perceptions for the real-world problems are significantly related to the ability to solve the pre-calculus problems. Results of the correlation analysis is $R = .55$, $p<.01$ for the real-world pre-calculus problems. Interest for the instructional tasks is significantly related the understanding of the pre-calculus problems $R = .72$, $p<.01$. Task understanding is significantly related to self-efficacy for the pre-calculus class $R = .60$, $p<.01$. In summary, elements of the instructional framework are significantly related to student achievement and motivation for learning pre-calculus.

While the assessment results for the framework are positive, the project team is developing strategies for those aspects of the framework that need improvement.

Qualitative Results

At the conclusion of the Fall 2003 semester the mathematics instructor indicated from his standpoint that the project "increased understanding and appreciation for pedagogy;" and is "straightforward to use since it places an instructor's teaching style in an education/pedagogy context;" and that the "Dimensions of Learning makes professors better teachers." These were free will, non-prompted remarks.

The students were asked the following questions: 1) What do you like about this course? and 2) What don't you like about this course? The instructor, computers, power-point presentations, interactive nature of the class and instructional tools appeared most often in students' responses in areas of most satisfaction. In general, students did not like the homework load, pop quizzes and using the Discourse for testing.

Conclusion

This reform effort has been a collaborative one among the Schools of Engineering, Science and Education in order to increase retention of engineering and computer science students. The course redesign is comprehensive and integrated, and is an aggressive approach utilizing the Dimensions of Learning pedagogy, performance assessment and technology to enhance student learning in freshmen mathematics courses. Preliminary results in terms of increased pass rates and also a higher level math enrollment are positive. The project team will continue this work.

The University is offering the redesigned Calculus I course this Spring 2004 semester and considering scaling up the course. Because this comprehensive approach involves a team of faculty, as a part of its on-going work the project team is seeking to develop a process and materials that will minimize future faculty's time in course development. The team believes that this is important in order to encourage others to utilize the pedagogy discussed.

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