Math Success for STEM Majors: Active Learning Strategies and Engineering Contexts

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Abstract

The *Math Success for STEM Majors* (2010–16) project (NSF STEP) was designed to increase the number of STEM graduates at Tennessee Technological University by pursuing six main strategies based in education research.[1] The two strategies relevant for this paper were: (1) incorporating active learning in the redesign of precalculus courses[2,3] and (2) integrating the STEM disciplines through context-driven mathematics applications within an "introduction to university life" course for entering STEM freshmen.[4] This paper describes the active learning strategies/modules that were designed and implemented by interdisciplinary teams of engineers, educators, mathematicians, and physics researchers in these redesign efforts. The strategies/modules have proven effective at motivating and retaining STEM majors at TTU and are transferable to other courses/institutions. Engineering educators can adapt/modify these for use in their respective contexts/settings.

Keywords

Active Learning Strategies; Precalculus Redesign; STEM Integration; Retention

Math Success for STEM Majors Project Summary

Tennessee Technological University (TTU) is the state's only technological university and its mission is to provide leadership and outstanding programs in engineering, the sciences, and related areas that benefit the people of Tennessee and the nation. Located in Cookeville and serving the notably rural Upper Cumberland region, TTU graduates 350–400 students (on average) in STEM majors annually. Our STEP Type 1A project, *Math Success for STEM Majors* (MSSM), proposed to increase the number of STEM graduates at TTU to 500 per year by the end date of the grant. The interdisciplinary Principal Investigator (PI) team consisted of Dr. Allan Mills (Chair, Department of Mathematics), Dr. Stephen Robinson (Chair, Department of Physics), Dr. Christopher Wilson (Associate Professor, Mechanical Engineering), Dr. Sally Pardue (Director, Oakley STEM Center and Associate Professor, Mechanical Engineering), and Dr. Holly Anthony (Professor, Curriculum & Instruction).

Based on previous surveys and investigations, the PI team identified success in mathematics as a key factor for retaining STEM students through graduation. The MSSM project had six strategies to increase the number of TTU STEM graduates. Those strategies were:

(1) incorporating active learning in the redesign of introductory STEM mathematics courses;
(2) implementing just-in-time academic support for students enrolled in all introductory STEM mathematics courses;

(3) integrating the STEM disciplines through context-driven math applications within an introduction to university life course for entering STEM freshmen;
(4) articulating mathematics skill-level expectations with selected high schools sending large numbers of STEM freshmen to TTU;
(5) implementing a uniform TTU mathematics course placement policy; and
(6) developing and implementing a data system that tracked individual student performance and status across the STEM disciplines.

The two strategies relevant for discussion in this paper are: (1) incorporating active learning in the redesign of precalculus courses[2,3] and (3) integrating the STEM disciplines through context-driven mathematics applications within a new introduction to university life course for entering STEM freshmen.[4] The MSSM project is best described as an "institutional change" project where large groups of students (first-time, full-time freshmen as declared STEM majors) are impacted via campus processes of (1) experiencing an active learning math course, and (2) experiencing a one-credit course which intentionally uses the related math.

The MSSM course redesign efforts for MATH 1730 (Precalculus) and MSCI 1020 (a STEM-flavored Introduction to University Life course) started with a two-day workshop on best practices in course redesign titled, "Design for Significant Learning Experiences," led by Dee Fink and Associates. The principles addressed at the workshop were used by the project team to redesign the targeted courses.

Precalculus Redesign and Active Learning Strategies

An introductory mathematics course, MATH 1730: Precalculus, was redesigned to include active learning strategies intended to improve student engagement and retention in the calculus sequence. *Active learning* within our project was defined in threefold as utilizing an automated homework system (WebAssign) to provide immediate feedback, replacing lecture time with engaging learning activities, and supplemental instruction by teaching assistants.

A redesigned version of MATH 1730 was used in 2 of the 6 sections offered in Fall 2011, with the remaining 4 sections taught in the traditional manner. (*Traditional manner* is defined within our project to indicate lecture-based instruction with 5 contact hours per week and no use of WebAssign.) The redesigned course was initially team-taught to facilitate further course development and contained 6 contact hours per week. In Spring 2012, the redesigned format was offered in all 3 sections of MATH 1730, team-taught, with a reduction to 5 contact hours per week. In Fall 2012, all five sections of MATH 1730 offered were delivered in the redesigned version and taught by individual faculty members. Changes were made to the course design each semester and current faculty continue to modify aspects of the course even though all sections are now offered in the redesigned format.

As a product of these redesign efforts, a handbook for teaching precalculus at TTU was created and is shared with all instructors of the course. It is intended to educate and guide instructors on active learning strategies. Key points highlighted in this manual include the importance of active learning through the use of engaging activities, cooperative/group work, appropriate questioning techniques (open and guided rather than closed and leading), using formative assessment classroom techniques, and selecting high-level tasks to leverage learning. A sampling of learning activities is also provided for instructors and they are encouraged to develop their own.

- Baseball Trajectory. Determine the flight path of a baseball and determine where it will hit the ground given parameters.
  - Math Concepts: Quadratic functions.
- Encryption. Encode and decode messages in the context of national security.
  - Math Concepts: One-to-one correspondence; inverse functions.
- Difference Quotient. Guided discovery investigation with 21 questions culminating in finding an expression for the slope of a secant line for a given function.
  - Math Concepts: Equations/graphs for tangent lines; slope of tangent line; secant line.

Another key component of the precalculus redesign was the use of Learning Assistants (LAs) to facilitate student learning outside of scheduled class sessions. Each section of MATH 1730 was staffed with a LA (undergraduate or graduate student who had passed MATH 1730 through MATH 1920 (Calculus II)) to attend all class sessions along with the students and to hold 5 office hours per week during which students could come to them for tutoring/mentoring and assistance. Some LAs also led study sessions and/or taught during one class session per week.

The pass rate in the redesigned course is higher than the historical rates in the traditional version of the course. Moreover, the pass rate of the "graduates" of the redesigned course in the subsequent Calculus I class has shown no decrease. Table 1 shows pass rates for fall semester sections. In Fall 2014, the minimum ACT Math score for entry was increased to 25—which accounts for the smaller number of students taking MATH 1730. Over the duration of the project, the average grade point average in MATH 1730 improved from 1.6 to 2.2.

Table 1 Pass Rates for Fall Sections of MATH 1730: Precalculus

	Fall 2010		Fall 2011				Fall 2012	
	FTF n=131	All Students n=211	FTF n=113	All Students n=154	FTF n=62	All Students n=76	FTF n=170	All Students n=225
ABC %	42.7%	43.6%	49.6%	45.5%	41.9%	43.4%	65.9%	58.7%
DFW%	57.3%	56.4%	50.4%	54.5%	58.1%	56.6%	34.1%	41.3%
Sections	5-Traditional Only		4-Traditional		2-Redesign		5-Redesign Only	

	Fall 2013	Fall 2014	Fall 2015
	All Students n= 198	All Students n= 133	All Students n=102
ABC %	50%	75.2%	71.5%
DFW%	50%	24.8%	28.5%
Sections	5-Redesign Only	4-Redesign Only	4-Redesign Only

Introduction to University Life Course Design

All entering freshmen (~ 2000 per fall) at Tennessee Technological University are required to enroll in a section of UNIV 1020, a one-credit "Introduction to University Life" course, intended to orient them to various academic, social, and administrative aspects of campus life. Some majors require a particular major-specific section intended to help students make early connections with their discipline, while other majors accept any version of UNIV 1020. The overarching goal of these courses is to help foster student success and so improve retention.

As part of the MSSM project a STEM-flavored version of this course was initiated with two specific additional goals: (1) to improve student attitudes towards mathematics through context-driven math applications, and (2) to appreciate the importance of multidisciplinary approaches in addressing STEM-focused problems. The approach used to address these additional goals was to design several active-learning modules that could be incorporated into this course. These modules are loosely based on the legacy cycle approach[5] and most involve applications of mathematics at either the precalculus or calculus-based level.

In the initial design phase, two interdisciplinary teams of engineers, educators, mathematicians, and scientists came together to brainstorm interesting contexts that could incorporate the desired mathematical and/or practical skills. Initial outlines of each proposed module were prepared and discussed and then the most promising were selected for full development by a smaller group of faculty. However, in the pilot implementation, it became evident that most students were not familiar with how to use a Microsoft Excel® spreadsheet to tabulate data, perform simple calculations, and create graphs. Therefore, two more short modules were developed with the primary goal of introducing students to these useful practical skills. The final modules naturally fall into three categories, and below we give a brief description of each, together with the mathematical concepts and/or practical skills incorporated.

Excel® skills development

- *Birthday Problem*. Determine the probability than in any group of *N* people, two or more of them have the same birthday.
    - Math concepts: Probability, factorial functions (optional).
    - Practical skills: Using Excel® to perform basic calculations and plot a graph.
- *Epidemic Evolution*. Investigate how the progress of an epidemic can be modeled mathematically.
    - Math concepts: Change versus absolute value. Recursive relationships.
    - Practical skills: Using Excel® to perform recursive calculations and plot graphs.

Short-term projects (1–2 hours)

- *Fluid Motion*. Investigate how the flow of water out of hole in a container can be modeled. Use results to determine a value for *g* (acceleration due to gravity).
    - Math concepts: Rate of change. Slope of graph.
    - Practical skills: Using Excel® to determine a line of best fit to a set of data.
- *Visualizing Motions*. Investigate how different types of motion can be represented using graphs of position, velocity, and acceleration.
    - Math concepts: Rate of change. Slope of graph. Introduction to derivatives. Trigonometric functions.
    - Practical skills: Use of probeware for data gathering.
- *Forces and Motion*. Investigate how the motion of an oscillating object is related to the force acting on it.

    - Math concepts: Trigonometric functions. Slope and derivatives. Introduction to differential equations.
    - Practical skills: Use of probeware for data gathering.

Long-term projects (Over 2 hours)

- *Building a Lunar Chair*. Design and build a functional chair that uses light, recycled, materials to be used on a lunar colony.
    - Practical skills: Using the engineering design process to solve a problem.
- *Building a Crystal Radio*. Research, design, and build a crystal radio.
    - Practical skills: Using the engineering design process to solve a problem.
- *How Fast can a Human Run?* Determine how the external forces acting on a running person lead to a maximum possible speed and model this mathematically.
    - Math concepts: Algebraic manipulations. Recursive relationships. Area under a graph (integral).
    - Practical skills: Breaking a complex problem into smaller steps.
- *Harvesting Exercise Energy*. Determine whether human motion can be an effective means to charge small electrical devices.
    - Area under a graph (integral). Surface of revolution (integral). Introduction to multivariable calculus.
    - Practical skills: Unit consistency. Concept of efficiency.

After using the university-wide UNIV 1020 course designation for the first year of the grant, in the second year the MSCI 1020 designation (for Math and Science) was created in the College of Arts & Sciences. Later, the course was also concurrently taught with a College of Engineering version, ENGR 1020. Toward the end of each fall semester a dedicated "showcase" event was held for students to exhibit their projects, including posters, videos, and live demonstrations.

Unfortunately for the project, departmental ownership of their own introduction courses was very high and and it proved difficult to populate the proposed number of sections of MSCI 1020. Thus, in later years the grant effort focused on disseminating module descriptions via dedicated workshops, helping instructors implement their own projects in their versions of the introduction course. As a result, the impact of the introduction course effort changed significantly over the duration of the grant. In the first three years, the various sections of MSCI 1020 reached 80–100 students each fall (up to four sections). However, when the grant effort changed its approach from implementation to dissemination, the potential number of students reached became much larger as over 500 STEM majors take various versions of the university life course each fall.

Student attitudes about STEM were captured with both pre-course and post-course surveys in the introduction course. Shifts in attitudes were compared with those from several ENGR 1020 classes that did not include any active-learning projects at that time. This survey revealed that all students' attitudes generally worsen over the course of their first collegiate term. However, in terms of the goals of this grant, those taking MSCI 1020 generally had better attitudes about their math courses than those who did not participate in any active-learning projects. Unfortunately, the student population in general seemed to have a drop in their enthusiasm towards STEM, as shown in Fig. 1. While there are undoubtedly other factors affecting these shifts in attitude, it is at least encouraging that participation in deliberately focused active-learning projects helps improve student attitudes toward mathematics.

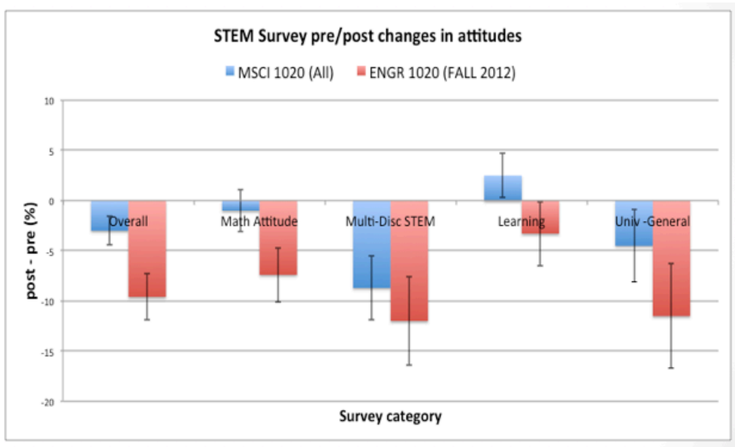

Fig. 1 Pre/Post STEM Course Attitudes

Conclusion

This paper described two key strategies of the MSSM project at Tennessee Tech University and highlighted the active learning strategies and modules that were designed and implemented with regards to the redesign of precalculus and the development of the MSCI 1020 course. These modules were developed by interdisciplinary teams of engineers, educators, mathematicians, and physics researchers and have been well-received by students and instructors. These active learning modules/activities have proven effective at motivating and retaining STEM majors at TTU, but we acknowledge that additional improvements can be made. It is our position that these strategies are transferable to other courses/institutions and programs and can be adapted/modified by engineering educators (and others in STEM) for use in their respective contexts/settings.

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