Engineering Education's Role in Improving Student Understanding and Learning of Mathematics and Sciences

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Abstract - Understanding science, technology, engineering and mathematics (STEM) topics and applications is a priority of the United States (U.S.). The State of Tennessee and its Department of Education (T.D.O.E.) are specifically interested in the effects of STEM initiatives on the employment prospects of citizens and the general economic growth of Tennessee. The state's goal is to expose students to engineering applications early with hopes of increasing the number of students interested in pursuing careers in STEM fields. However, teachers are often underprepared to discuss such careers and to teach such curricula. This paper presents two initiatives at the University of Tennessee at Chattanooga (UTC) that prepare teachers to address the STEM needs. One, UTeaChattanooga, prepares students pursuing four-year degrees in STEM fields to obtain licensure at the secondary education level to teach math and science. The other, Technology/Engineering + Literacy = Mathematics Understanding (TELMU), introduces in-service teachers to activity-based learning exercises that increase mathematical and science aptitude through engineering applications.

Keywords: STEM Education, STEM Initiatives, STEM K-12

INTRODUCTION

It is strongly believed that for the U.S. to compete globally, the work force must be grounded in science, technology, engineering, and math (STEM) disciplines [1]. Studies indicate that during the next decade, the U.S. demand for scientists and engineers is expected to increase at four times the rate of all other occupations [2]. However, data from studies such as the National Science Foundation's *Survey of the American Freshman* [3] and the 2007 and 2009 National Assessment of Educational Progress Report [4] [5] state that

- both mathematics and science continue to be academic stumbling blocks for a large number of students
- a low number of students are pursuing degrees in technical fields.

As noted in a U.S. Department of Labor study, "Long-term strategies to maintain and increase living standards and promote opportunity will require coordinated efforts among public, private, and not-for-profit entities to promote innovation and to prepare an adequate supply of qualified workers for employment in STEM fields. American pre-eminence in STEM will not be secured or extended without concerted effort and investment" [6]. Additionally, it is noted by the National Science Foundation, as well as the United States House of Representatives, that engineering is crucial to moving our nation into the 21st Century and to enhancing our national security and global competitiveness. The U.S. House of Representatives passed a resolution "recognizing modeling and simulation [engineering] as a National Critical Technology important to the security and prosperity of the U.S." [7]. Moreover, in 2006, an NSF Blue Ribbon Panel noted that "computer simulation [engineering] has become indispensable to the development of all other technologies" and "promises to revolutionize the way engineering and science are conducted in the twenty-first century" [8]. However, without the pre-requisite math and science skills needed to solve such problems and use technology, fewer students are going into these disciplines. In addition, the number of available and qualified individuals who can replace the jobs of the retiring employees is nowhere near the needed amount.

To combat this issue, the T.D.O.E. incorporated engineering and technology standards into the integrated science and math curriculum. [9] Also, the State of Tennessee applied for Race to the Top funds from the federal government and was awarded one of the first two grants in the nation. This infusion of seed money allowed the state to add many needed STEM programs such as STEM platform schools and hubs, UTeach programs at three

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universities across the state, and the Technology/Engineering + Literacy = Mathematics Understanding (TELMU) Academy in the Southeast Tennessee region. These programs intend to retain STEM talent in Tennessee and both foster student interest in and keep students invested in STEM subjects, thus preparing them to succeed in pursuing STEM careers.

RATIONALE

"Developing a curriculum does not guarantee that engineering education in K–12 will be successful. A critical factor is whether teachers—from elementary generalists to middle school and high school specialists—understand basic engineering concepts and are comfortable engaging in, and teaching, engineering design. For this, teachers must either have appropriate background in mathematics, science, and technology, or they must collaborate with teachers who have this background". [2] This statement from the National Academy of Engineering's study *Engineering in K-12 Education* is precisely why the work of UTeaChattanooga and the TELMU Academy is so essential. Having qualified, certified teachers that have degrees in STEM disciplines will not only help student understanding through a teacher's depth of content knowledge, it will also assist the educational community with staying connected to the most cutting-edge research and job opportunities to excite students and engender interest in STEM.

PROGRAM OVERVIEWS

UTeaChattanooga and the TELMU Academy address the need for qualified, certified teachers in STEM disciplines from different perspectives. UTeaChattanooga prepares college students to be successful Math and Science teachers. TELMU takes present Math and Science teachers and provides them instruction and tools in activity based and literacy based teaching and learning to improve their present teaching strategies.

UTeaChattanooga

The UTeach program was developed at the University of Texas at Austin in 1997 to assist students wishing to pursue degrees in STEM fields to also obtain teacher certification, with the hopes this will increase the number of highly qualified STEM teachers in K-12. [10] This program also provides support in terms of mentors and monetary rewards to graduates of the program to assist them in staying on track in their education career to reverse the "burn out" trend seen among secondary teachers within their first three years.

UTeaChattanooga is one of 22 nationwide replication sites of the first UTeach program created in Austin. UTeaChattanooga is a cooperative program between three colleges (Arts and Sciences, Engineering and Computer Science, and Health, Education, and Professional Services) and 7 departments (Applied Math, Biology, Chemistry, Geology, Physics, Computer Science, and Engineering). UTeaChattanooga is the only UTeach program in the nation that includes an Engineering degree. In this concentration students obtain a BSE degree from an ABET-accredited program (thus can sit for the Fundamentals of Engineering exam) and obtain the education necessary to sit for state teaching licensure exams in secondary Math and Physics. [11] The engineering degree curriculum program is shown in Table 1.0.

UTeaChattanooga was started due to dismal numbers of STEM teaching graduates being produced by Tennessee universities. For instance, in 2010 only 2 qualified physics teachers graduated from all Tennessee universities. Also, over the past 3 years, UTC, which has a well-respected Education program, graduated an average of 8 STEM teachers per year out of an average of 141 total certified Education graduates. [12] Adding Engineering students to the mix of UTeach students helps to increase the possible number of students certified to teach Calculus and Physics.

Master Teachers and UTeach trained faculty administer the UTeach curriculum alongside the major course of study. Students take a 1 hour Step 1 course and 1 hour Step 2 course before being formally admitted to the program. These courses give students insight into teaching at both the elementary and middle school levels and allow them to do field work in the schools to determine if the profession is a good fit for them. If they earn a C or better in the course they are reimbursed the maintenance fees ($225 for the one credit hour course at UTC for the 2011-2012 academic year), regardless of whether or not they decide to continue the program. After this, students apply to the UTeaChattanooga program and, if accepted, take the Knowing and Learning, Classroom Interactions, Perspectives in Science and Mathematics, Research Methods, and Project Based Instruction courses that emphasize teaching and learning of the math and science disciplines.

The students continue to do field work throughout their four years of study. Their curriculum culminates with apprentice teaching during their last semester. By this time they are already comfortable in the classroom due to their previous field work.

Table 1.0: UTC Engineering (ENGR): UTeach Curriculum

First Semester				*Second Semester*		
FRESHMAN						
ENGL 1010	Rhetoric & Composition 1	3		ENGL 1020	Rhetoric & Composition 2	3
ENGR 1030	Basic Engineering Sci	3		ENGR 1040	Vector Statics	3
ENGR 1030L	Basic Engineering Sci Lab	1		ENGR 1850	Intro Engr Design	2
MATH 1910	Calculus 1	3		ENGR 1011	Intro to 2D & 3D Modeling	1
MATH 1911	Calculus 1 Lab	1		MATH 1920/21	Calculus 2/lab	4
CHEM 1110	General Chemistry 1	3		MATH 2200	Elementary Linear Algebra	3
CHEM 1110L	General Chemistry 1 Lab	1		UTSM 1020	Step 2	1
UTSM 1010	Step 1	1				
Total		**16**		**Total**		**17**
SOPHOMORE						
ENGR 2700	Electric Circuits 1	3		ENGR 2220	Prob & Statistics Engr	3
ENGR 2700L	Electric Circuits 1 Lab	1		ENGR 2460	Mechanics of Materials	3
ENGR 2250/224(	Engineering Programming	3		ENGR 2460L	Mechanics of Materials Lab	1
MATH 2450	Intro Differential Equations	3		ENGR 2480	Dynamics	3
PHYS 2310	Prin of Physics E & M	3		MATH 2550	Multivariable Calculus	3
PHYS 2310L	Prin of Physics E & M Lab	1		UTSM 2020	Classroom Interactions	3
UTSM 2010	Know & Learn	3				
Total		**17**		**Total**		**16**
JUNIOR						
ENGR 3520	Engineering Economy	3		ENGR 3700	Energy Conversion Electronics	3
ENGR 3050/303(	Thermo-Fluids	3		Engr Disc	Select Discipline Course	3
Engr Disc	Select Discipline Course	3		ENGR 3280	Control Systems	3
UTSM 3010	Perspectives*	3		ENGR 3280L	Control Systems Lab	1
UTSM 2300	Functions and Modeling	3		Culture & Civs	from Non-Western list	3
				UTSM 3020	Research Methods	3
Total		**15**		**Total**		**16**
SENIOR						
Engr Disc	Select Discipline Course	3		ENGR 4850	Interdisciplinary Design 2	3
Engr Disc	Select Discipline Course	3		Fine Arts	from Fine Arts list	3
ENGR 3850	Interdisciplinary Design 1	3		Behavioral/Social Sc	from Beh. Soc Sci list	3
Behavioral/Soci	from Beh. Soc Sci list	3		UTSM 4020	Apprentice Teaching	6
Engr Disc	Lab or course	1/2/3				
UTSM 4010	Proj-Based Instruction	3				
Total		**16**		**Total**		**15**
Total Hours:	**128**					

TELMU Academy

The focus of the TELMU Academy is to provide participants, present certified math and science teachers, with hands-on experiences that strengthen their pedagogical content knowledge in grades 6-9 mathematics through the use of inquiry-based and activity-based science. This is addressed by using (1) curricular materials involving engineering and technology to support Tennessee's process and content standards in mathematics as well as inquiry standards in science, (2) research-based reading strategies to strengthen student comprehension of STEM content disciplines, and (3) literacy lessons to strengthen comprehension. This project uses nationally developed activities found successful at the middle school and 9th grade levels. The activities are specifically successful at introducing students to engineering principles that enhance scientific and mathematical literacy. TELMU is supported through funding by the Tennessee Higher Education Commission (THEC).

The TELMU experience involves 40 teachers from six school systems surrounding Chattanooga, with at least one math and one science teacher from each school. The TELMU experience emphasizes technology-based and

engineering-based activities related to middle school and Algebra I standards that are problem areas for students. (Recognized problem areas include applying mathematics to novel situations, developing mathematical models, manipulating formulas, solving literal equations, analyzing patterns, interpreting slope, and working with functions.) Each activity begins with an introduction to relevant STEM vocabulary and key metacognitive strategies, such as questioning and visualizing [13], continues with the teachers assuming the roles of students to complete the activity, and ends with the participants returning to their teacher roles to debate the activity's learning outcomes. Near the end of the TELMU Academy the teachers will practice creating or adapting their own activity-based activities.

The twelve month TELMU Academy begins at a one day workshop where the project team gains an understanding of present teaching practices and experiences of the teachers. The teachers then experience a two week summer workshop at UTC where they participate in and develop activity-based lessons in Math and Science. In the fall the project team assesses how what was experienced in the summer workshop has been adapted or used in the teachers' classrooms. Table 2.0 illustrates the time line of TELMU project activities.

Table 2.0: Participant Project Activity

Date	Activity	Location	ContactType	ContactHrs
Jan '12	Attend pre summer workshop	UTC	F2F	8
Spring '12	Video classroom lesson/activity	Home School	IND/TM	
June '12	Participate in summer workshop	UTC	F2F	80
Fall '12	Participate in on-line collaboration	Home School	Virtual	16
Aug/Sept '12	Video classroom lesson/activity	Home School	TM	
Sep/Oct '12	Attend 1st post summer workshop	UTC	F2F	8
Oct '12	Attend 2nd post summer workshop	UTC	F2F	8

Note: F2F (face to face), IND (individual), TM (team)

A number of TELMU activities are adapted from TeachEngineering [14]. This site provides teacher-tested, standards-based K-12 engineering lessons. These lessons are hands-on, comprehensive, and relevant to students' lives. They also are mapped to Common Core Standards and state standards. Other activities are adapted from the Project Lead the Way (PLTW) curriculum [15]. PLTW provides rigorous, relevant STEM education for middle and high school students. The curriculum is engaging, hands-on, and designed to encourage the development of problem-solving skills, critical thinking, and creative and innovative reasoning.

The goal of the TELMU experience is to provide the teachers with a repertoire of project-based strategies that increase student engagement and thus strengthen retention of mathematical concepts and processes. The teachers experience learning from the learner's point of view, determine how the learning occurs from the lesson, and then help build new lessons that develop mathematics and science content in a variety of contexts and pique student interest. TELMU helps teachers develop the necessary strategies that improve the ability of students to comprehend problem situations containing quantitative information, develop their ability to use mathematics in context, and extend their knowledge of other core subject areas [16].

DISCUSSION

UTeaChattanooga

UTeaChattanooga is in its second year and has already seen tremendous growth in the number of students interested in becoming teachers in STEM disciplines. The number of students enrolling in Step 1 and Step 2 courses has grown from 31 in Fall 2010 to 32 in Spring 2010 to 59 in Fall 2011. Of those students starting in the 2010-2011 academic year, 32 have continued in the program yielding a 50.8% retention rate, with this expected in increase to 80% by the end of the 2012-2013 academic year. Once all of the courses are fully staffed and running by the end of the 2012-2013 academic year, the expectation is to have 120 students fully admitted to the program. [17]

Students have been placed for field experiences in elementary, middle, and high schools. The cohort of schools that accept these students for field work has grown from four in Fall of 2010 to seven in Spring of 2011 and to ten in Fall of 2011. Figures 1.0 and 2.0 show UTeach

Figure 1.0 UTeach Student in Middle School

students using lessons they developed to teach middle and elementary school students.

Nationally, UTeach has proven to be an effective program in that 90 percent of UTeach graduates enter the teaching profession, 80 percent of UTeach graduates are still teaching in five years, and 45 percent of these graduates teach in high-need schools. Also, these students tend to have excellent academic records and are given the opportunity to pursue research in the summers at Department of Energy Labs, their home universities, and other institutions through such funding mechanisms as the NSF Robert Noyce grant.

Figure 2.0 UTeach Student in Elementary Class

TELMU Academy

Obtaining participates for the TELMU Academy was not difficult. Twenty pairs of math and science teachers for the 6^{th} – 9^{th} grades from 5 different school districts were quickly identified. TELLMU required teachers to come from schools in at least sets of two so teachers can more easily connect with teachers who are equally interested in learning new teaching techniques. The participants range from teachers with 1 year of expereince to teachers with over 30 years of experience.

The TELMU project officially kicked off with teacher participation the third weekend of January 2012. The kick off workshop was well attended and much discussion occurred in regards to how the teachers believe students are learning or are not learning math concepts. The teachers were enthusastic to participate with the mix of science and math teachers to discuss the relationship between learning math and applying math. They especially welcomed the open discussion format of the workshop and openly expressed the difficulties they find teaching their present students. The TELMU project team was able to collect much data that will help them to further develop the necessary activity lessons to support this particular population.

The two week TELMU Academy summer workshop is scheduled for June. This workshop will be followed with two fall one-day workshops to track the progress of the teachers to embed what they learned during the summer in their lessons. In addition, to assure the results of TELMU are lasting, the program will provide continuation of communication between participants and mentors through a common website wiki. The subsequent conversations and sharing of knowledge allow the expansion of each teacher's resources as well as a place to find answers to basic teaching and knowledge questions that can aid a teacher's ability to properly convey this new methodology to students.

In addition to assuring that teachers have support when they return to the classroom, the following evaluation measures are planned to determine how well the TELMU project (1) affects teachers' knowledge of mathematics, other STEM areas and literacy strategies, (2) impacts teachers' pedagogical content knowledge and instructional practices, and (3) improves student achievement in mathematics and science.

- Participating teachers will complete a pre/post assessment of mathematical content knowledge. This assessment will provide a measure of the growth of teachers' knowledge of selected mathematical facts, concepts, and processes included in the current Tennessee Mathematics Curriculum Framework and the Common Core State Standards and addressed in the project. Both the Framework and the Standards emphasize major objectives of this project, including "applying mathematical ways of thinking to real world issues and challenges," "apply[ing] mathematics to novel situations," and "emphasize[ing] mathematical modeling". [18]
- Project leaders will conduct both formative and summative evaluations of activities developed and presented by teams of participants.
- Project leaders will conduct both formative and summative evaluations of lesson plans developed by participants to implement in their systems.

CONCLUSIONS

While the current state of STEM education is one of high needs with low resources, the recognition that this is not conducive to the U.S. economy and future stability is clearly posited. Thus, programs like UTeach and the TELMU Academy are being funded across the country to curtail the tide of STEM defection, train teachers to touch this generation of technologically savvy learners, and help this nation regain high K-12 educational status. There have been many preliminary results that point to a rise in STEM aptitude and interest. UTeach and UTeaChattanooga are already showing that they are contributing to the positive results. It is believed that the TELMU Academy will also be a contributor to increasing STEM knowledge and STEM participation. If the evaluation concurs, the plan is to make the Academy available to a much larger population through program growth and dissemination.

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