STEMteach: PREPARING THE NEXT GENERATION OF MATHEMATICS AND SCIENCE TEACHERS

G. BUNN, D. DAILEY, and A. COTABISH
Dept. of Teaching and Learning, University of Central Arkansas
Conway, AR 72035
Garyb@uca.edu

Abstract

With an increasing demand for individuals prepared in Science, Technology, Engineering, and Mathematics (STEM), one university responded to this call by changing its teacher preparation program. Better-prepared mathematics and science teachers have the opportunity to engage and excite students, thereby preparing and promoting more of them to enter the STEM professions. The described program is a replication of the national UTeach model that recruits content majors in mathematics and science to explore the teaching profession during a first-semester course that includes an early field experience in the elementary grades. This field experience is designed to be engaging for both the teacher education candidates and the elementary students in an effort to demonstrate the joy of teaching and to retain the candidates in the program. The ultimate goal of the program is to increase the production of quality secondary mathematics and science teachers who can transfer their own deep understanding of their content to students so that these students will be career and college ready in the STEM disciplines.

In a small college freshman classroom at the University of Central Arkansas (UCA), fourteen young men and women are grouped at tables and asked to pretend that they are third-grade students. Laid out before them are various black canisters filled with cotton swabs doused with household scents. Students are instructed to classify the unknown scents (cinnamon and lemon) by smell. A University clinical instructor facilitates the lesson by asking students to contemplate and classify the unknown scents on a T-chart while she models effective teacher pedagogy through inquiry-based instruction. Students further explore different ways to classify and sub-classify various types of seashells. Student groups explain that their classifications are based on various characteristics of the seashells, including size, color, type, and shape. The instructor clarifies that these characteristics are called physical properties, and that this system is a common way to classify matter. At the conclusion of the lesson, the freshmen are asked to compare and contrast open versus guided instruction using the 5E Learning Cycle (Engage, Explore, Explain, Extend, and Evaluate); then, to consider the type of instruction that spurs

independence, problem-solving, and initiative. The instructor goes on to state, "We are striving for open confidence. The real world is not a worksheet!"

At first glance, the college class would appear to be a typical pre-service teacher education class; however, students in this classroom are mathematics and science content majors who are participating in an innovative college program, STEMteach, housed at the University of Central Arkansas. With the hopes of promoting teaching as a career choice among STEM majors, STEMteach students will graduate with a content degree in mathematics or science, as well as a teaching license. They are taught by a seasoned Master Teacher whose expertise is in K-12 mathematics. During their tenure as college freshmen, these students will participate in the typical track of science and mathematics courses found in universities around the country as well as complete teacher education classes that require them to conduct classroom observations and teach students beginning in their first semester of coursework.

University of Central Arkansas STEMteach is a mathematics and science teacher preparation program that models the innovative UTeach program, which began at the University of Texas in 1997. The strength of the UTeach model lies within its unique collaboration between Colleges of Natural Science and Mathematics, and Colleges of Education. The program is distinctive in its early, intensive field experiences for teacher candidates, the use of Master Teachers as instructors, and the development of teacher candidates' content knowledge and effective teaching strategies. The program has the following goals: 1) to attract and retain more and better students to secondary mathematics and science career paths; 2) to establish an enriching curriculum that integrates modern technological teaching tools with opportunities to experience the joy of scientific discovery and problem solving, and a mastery of the content; and, 3) to prepare outstanding mathematics and science teachers who are leaders of their discipline, integrate technology to enhance the classroom, and involve students in inquiry-based learning. As an added benefit, students can earn a Bachelor of Science in Mathematics or Science and a teaching license within four years. This unique opportunity provides students additional career options after graduation with no additional time or expense, while still allowing them the opportunity to pursue graduate or professional schools if they wish.

The Increasing Demand for a STEM-Prepared Workforce

The STEMteach initiative was created to respond to the national, state, and local need to increase mathematics and science teachers. Specifically, the national call for an increased and a better-prepared workforce in Science, Technology, Engineering, and Mathematics (STEM) is

widely documented. The Brookings Institute, an organization that conducts research on a broad range of issues, suggested, "Workers in STEM fields play a direct role in driving economic growth," and revealed that one in five of all United States jobs needs a significant background in at least one of the STEM disciplines [1]. To put this in perspective, in 2011 alone, 26 million jobs in the United States were reliant upon workers trained in a STEM discipline. Data from the United States Bureau of Labor Statistics supported these findings, classifying ninety-seven jobs as "STEM occupations," such as jobs and careers in mathematical and computer sciences, engineering, architecture, medicine, management, education, manufacturing, and sales [2]. The Bureau found that this high demand for workers skilled in STEM disciplines translated to higher salaries for these employees who earned an average salary of $77,800. This exceeds the average annual salary for all occupations in the United States by nearly $35,000 [2].

Regrettably, our education system appears to be falling short when preparing students for STEM-related careers. "Change the Equation" is an alliance of leaders representing the business communities who have an interest and a stake in the increased availability of a highly trained STEM workforce, and who are devoted to improving STEM teaching and learning. In 2012, the group released "Vital Signs," a report that described the status of STEM education in the United States, which revealed, "Across the STEM fields, job postings outnumbered unemployed people by almost two to one" [3]. For occupations in healthcare that required STEM preparation, the gap was even wider with over three job postings for every unemployed person. In comparison, the number of unemployed people for all occupations outnumbered the available jobs by nearly four to one.

Motivating and Nurturing STEM-Talented Learners in the K-12 Classrooms

With the documented shortfall of STEM talent in the United States, the need to motivate and support STEM talent rests squarely on the capacity of our education system to identify and nurture ability [4]. To facilitate the development of STEM innovators, the National Science Board (NSB) recommended that K-12 students have investigative, real-world experiences in STEM learning. In particular, they recommended students be engrossed in inquiry-based learning that is centered on real-world problems. In response to this need, the NSB encouraged STEM teachers to participate in programs that utilized inquiry-based learning and that emphasized the importance of both content knowledge and pedagogy in their practices. The U.S. National Commission on Mathematics and Science Teaching for the 21st Century and the recently released "Vital Signs" also maintained that, to better prepare students for the STEM workforce, teachers must have a deep knowledge of their subject matter, and it was recommended that preparation

programs focus on providing candidates with a clear understanding of content knowledge and the most effective instructional methods [3, 5].

Current Status of STEM-Prepared Teachers

As indicated by recent reports, many K-12 STEM teachers have not had the educational experience necessary to develop their content knowledge or pedagogy. For example, in elementary grades, Fulp found that less than 5% of elementary teachers received undergraduate degrees in science and 40% took four or fewer undergraduate courses in the subject [6]. In addition, the National Research Council reported that many teacher preparation programs only required two courses in mathematics for future elementary teachers [7].

Secondary teachers are typically more prepared in their specific discipline; however, many are teaching out of their content area. For example, Augustine reported that 69% of students in grades 5-8 were taught by mathematics teachers who were either not certified or did not have a mathematics degree [8]. In addition, an alarming 93% of middle school physical science students did not have a teacher who was certified or who possessed a degree in physical science. The trend continued in high school (31% mathematics; 61% chemistry; 67% physics) with teachers not being certified or having a degree in their subject area. Change the Equation reported similar results [3]. They found that only 31% of eighth graders were taught by teachers with undergraduate degrees in mathematics and only 48% of their science teachers had degrees in science.

When teachers lack content knowledge in their assigned teaching discipline, the effects resonate throughout the classroom. For example, in a review of literature, Tairab found that science teachers exhibited hesitancy, and struggled to deliver effective instruction when their knowledge of content was limited [9]. In particular, Tairab reported that teachers often neglected effective teaching methods, such as inquiry-based learning and open discussion, and utilized textbook learning and independent seatwork instead. In further support of strong content preparation, Rosenberg, Heck, and Banilower found a positive relationship between teachers' establishment of an investigative classroom environment and the number of content courses they took in college [10]. As indicated by these studies, teacher subject-matter knowledge is a necessary ingredient in effective teaching.

To address issues with content knowledge, Tairab recommended teacher education programs emphasize a deep level of content attainment among prospective teachers [9]. Tairab

suggested subject-matter specialists and education specialists devise plans to ensure that prospective teachers gain the content knowledge and pedagogical skills needed to be effective teachers, an approach that is a hallmark of the UTeach teacher preparation program. The UTeach students graduate with undergraduate degrees in STEM disciplines as well as with teaching licenses, acquiring a deep level of subject-matter knowledge in their undergraduate fields and developing their pedagogical skills through their education courses [11]. Throughout their four years of college, these students put their content knowledge and pedagogical skills to practice during multiple opportunities of observing and teaching in classrooms. These experiences are integrated into their pedagogy courses, not isolated events, and allow them the chance to hone their teaching craft in authentic environments. Currently, thirty-four universities replicate the UTeach program, producing more than 1,600 teachers. At the University of Texas at Austin, 90% of UTeach graduates enter the teaching profession and nearly 80% of those are still teaching five years later—both of these rates exceed the national average [12].

Responding to the Call

In August 2011, Arkansas Governor Mike Beebe announced the creation of "STEM Works," an initiative whose primary purpose was to increase the number of well-prepared STEM students within the state. The focus on STEM resulted from the Governor's Workforce Cabinet's determination that developing students in these areas has the greatest potential for promoting economic growth in the state [13]. The initiative identified three programs for students in grades K-12 and one program for higher education. The K-12 programs were "Project Lead the Way," "New Tech High Schools," and "EAST Core." The program for higher education was a replication of the UTeach model. All of these programs employ an inquiry-based, investigative approach to learning, an approach that has proven to increase student achievement and engagement [14, 15].

To fully realize the potential of the three K-12 programs and to ensure that all students in the state were receiving a quality education in the STEM disciplines, the group recognized the need for well-prepared mathematics and science teachers in every classroom and for a pipeline of highly qualified teachers to continue to support these initiatives. Supporting the National Science Board's call for "rigorous, research-based STEM preparation for teachers" through the combination of research, theory and practice, the UTeach model specifically targets those students seeking a Bachelor of Science in Mathematics or Science who may not have previously considered the teaching profession [4]. Universities in the state competed for grant funding and approval to replicate the program, and three universities were approved and began

implementation in Fall 2012. This article specifically focuses on program implementation at one of the three universities chosen to replicate the model.

Implementation of STEMteach

All universities who are approved to replicate the model commit to the publication, *UTeach: Elements of Success*, which includes the use of dedicated master teachers, collaboration between colleges, and early and intensive field experiences [11]. Programs also agree to establish a distinctive program identity. At the University of Central Arkansas, the program was branded as "STEMteach" to coincide with other programs at the University, such as the "STEM Residential College" and the "STEM Institute." The program identity aids in the marketing and recruitment of candidates who have typically not considered teacher licensure as an option. Often, candidates who pursue a Bachelor of Science in Mathematics or Science do not consider teaching as a career path. As an example, in 2012-2013, the University of Central Arkansas had over 1,000 STEM majors, but only seventeen sought a teacher's license. To attract these students to STEMteach, program identity and recruitment are critical to the success of the program.

To recruit candidates into the program, candidates begin with a one-hour, 1-credit course entitled, *Step 1: Inquiry Approaches to Teaching* which introduces them to inquiry-based learning and offers candidates an opportunity to explore teaching without a commitment. Mathematics and science majors are accustomed to experimenting and investigating so the methods of the course are appealing to most. In the first semester of the program, candidates observe and teach three lessons in a third or fourth grade classroom rather than in grades 7-12 classrooms. Although candidates are completing requirements for secondary licensure, working with students in earlier grades allows candidates to experience teaching in a low-risk environment while focusing primarily on the practice of teaching. These first teaching opportunities are designed to ensure successful experiences for the candidates, understanding that their first impressions of the profession are likely to shape their long-term opinions.

In the second semester, candidates continue to explore teaching in the course *Inquiry-Based Lesson Design*, known to students as "Step 2." Following a similar approach as Step 1, this class gives candidates the opportunity to develop and perfect lessons in the University classroom and then teach those lessons to students in area schools, this time to middle school students. All lessons, from both Step 1 and Step 2, are designed to be age-appropriate and to be highly engaging for the students. Again, the goal is to create successful experiences for the candidates and to deliver beneficial lessons for the local school students. Early success is

important. As candidates experience the joys of teaching, the motivation to join the profession increases which, in turn, improves the chances that candidates will continue with the program. UTeach Institute data indicate that, on average, 60% of those who take Step 1 will enroll in the Step 2 class [16]. To further remove obstacles and to encourage them to continue in the program, students who successfully complete these first two introductory courses receive tuition rebates so that there is no expense for exploring these classes.

Unlike most traditional teacher education programs, the UTeach model gives candidates the chance to experience teaching from the first day in the program while continuing to pursue their academic goals of a baccalaureate degree in mathematics or science. Convincing mathematics and science majors to *try out* the program is the most prevalent challenge to date. Focusing introductory classes on the practical rather than on the theoretical is appealing to students, and leads many to take what is perceived to be a "fun class" merely for the experience. Once enrolled, program faculty can demonstrate the importance and rewards of teaching to candidates who likely would never have encountered them, thus promoting the opportunity to recruit candidates to the program. Based on national trends, 43% of candidates who enroll in the first course will complete the program, a rate that represents a significantly higher potential production of mathematics and science teachers than the institution's current program.

In the 2012-2013 academic year, the University had thirteen candidates complete the mathematics education program for teacher licensure, which was considerably higher than the previous three-year average of eight candidates. The production of science teachers was fewer, with only two completing the program in life science and two in physical science. While the life science numbers for the last year were on par with previous years, the two candidates in physical science were the first to complete that program in the past three years. This level of production of mathematics and science teachers is inadequate and insufficient to meet the demands of the state's school system.

Since its inception at the University of Central Arkansas (UCA) in 2012, eighty candidates have participated in the STEMteach program. Beginning with the Fall 2012 group of nineteen, the incoming class of Fall 2013 has increased to fifty-one students enrolled in the first course (Step 1), and seventy-one students are currently enrolled in at least one class in the program. While the growth is encouraging, there is room for even greater growth. Table 1 represents the numbers of STEM majors enrolled at the University during the past four years. Assuming the UTeach Institute projection of 43% of those who take the first class will progress to

program completion, recruiting just 10% of the STEM majors at the University to take the first course would increase production of mathematics and science teachers from the 2013 total of seventeen to nearly fifty candidates over the course of four years [16].

Table 1
Total Number of STEM Majors

Content Area	2009	2010	2011	2012
Biology	655	649	640	645
Chemistry	120	130	126	126
Computer Science	126	121	160	194
Mathematics	142	147	130	130
Physics and Astronomy	51	69	58	68
Total	1,094	1,116	1,144	1,163

The UCA STEMteach is positioned to help provide mathematics and science teachers for our state, teachers who will be equipped to respond to the increased need for content knowledge of the Common Core State Standards and the Next General Science Standards. The Common Core State Standards (CCSS) in mathematics shift our approach for educating students about the subject [17]. Two of those shifts, coherence and rigor, require a deeper understanding of content knowledge, the depth of knowledge that content majors will likely have. The new standards call for mathematics students to think across grades and to link topics within the grades. The CCSS are more rigorous, going more deeply into fewer topics, requiring conceptual knowledge, procedural fluency, and application. Teachers with degrees in the content will have the necessary background to make both of these shifts, as well as sufficiently address the eight mathematical practices of the standards.

In addition, the Next Generation Science Standards (NGSS) requires similar shifts. Students will explore content in greater depth and complexity while engaged in the practices of science and engineering. To further deepen student understanding of science content, crosscutting concepts will be used to link core ideas within and across grade levels—thereby creating a coherent progression of knowledge as students advance through school [18]. As with the CCSS, the NGSS requires a more rigorous study of science content, further evidence of the

need for teachers to have a greater depth of knowledge along with the pedagogical strategies to deliver this content.

Conclusion

Recall the classroom described in the introduction of this article. The students are in their first semester of STEMteach, and soon they will be observing and teaching a lesson in an elementary classroom. By the time they finish their undergraduate degrees, they will be prepared to enter the classroom, armed with content knowledge and pedagogical skills. Equally important are the valuable experiences each student has gained from observing and teaching classes in elementary, middle, and high schools. These students are offered experiences not typically found in pre-service teacher education, including the chance to graduate with a content degree and the opportunities for student teaching beginning in their freshman year.

The implementation of STEMteach and other innovations like it are not only important, but necessary. Adoptions of such innovations are cause for teacher education as a field to reflect on its role in supporting and increasing the number of STEM teachers. The field of teacher education has not always been so open-minded. With traditional teacher preparation programs no longer meeting the demand to produce mathematics and science teachers, and the adoption of the new CCSS and NGSS and their national focus, it becomes critical for the field to be creative and embrace such innovations.

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