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Engineering Education Partnership*

T. J. SILLER, M. A. DE MIRANDA and D. C. WHALEY
College of Engineering, Colorado State University, Fort Collins, Colorado, Fort Collins, CO 80523-1301, USA. E-mail: tjs@engr.colostate.edu

Colorado State University has created a joint education–engineering degree program between the School of Education and the College of Engineering. The objectives for developing this new program include: to improve secondary education through highly qualified technology teachers; to place engineering graduates in the secondary classroom where they can encourage a more diverse group of potential engineering students at an early age; to attract a more diverse student population into engineering undergraduate programs; and to better prepare students in science, technology, engineering, and mathematics (STEM) for entering into an engineering undergraduate program. The study of engineering in education helps create a citizenry that is highly literate, disciplined, is capable of thinking critically and creatively, is knowledgeable about a range of cultures, and is able to participate actively in discussions about new discoveries and choices. Colorado State University is taking a leadership role in initiating systemic change that will positively influence the future of all K-12 education. This new joint degree program is built on new partnerships across traditional academic and disciplinary lines to innovate, cooperate and prepare highly qualified teachers.

Keywords: technology education; K-12, education; partnerships; engineering science; diversity

INTRODUCTION

COLORADO STATE UNIVERSITY'S COLLEGE OF ENGINEERING has created a joint education–engineering degree program in cooperation with the School of Education. One of the distinguishing features of this new program is that students receive a nationally accredited engineering degree (Accreditation Board for Engineering and Technology, ABET) along with a nationally accredited technology education teaching license (National Council for Accreditation of Teacher Education, NCATE). The objectives for developing this new program include: improving secondary education through highly qualified technology teachers; the placement of engineering graduates in the secondary classroom where they can encourage and support a more diverse group of potential engineering students at an early age; attract a more diverse student population into engineering undergraduate programs; and better prepare students in science, technology, engineering, and mathematics (STEM) for entering into engineering undergraduate programs. This program is an explicit implementation of the concept that an engineering degree can serve as the foundation for non-engineering careers, in this case the secondary teaching profession.

Given the declining numbers of students pursuing careers in engineering, and the need to attract underrepresented minorities and women into science and engineering, the engineering profession has great interest in strengthening the educational pathways to engineering for K-12 students. Science, technology, engineering and mathematics tenets naturally intertwine in engineering practice and their applications brought to the K-12 classroom can provide powerful contexts for authentic learning emphasizing engineering design. The relationship between science, technology, engineering and mathematics is cyclical, with each area relying on the other for advancement. For example, as scientific research discovers a new composite material, technological designers and engineers seek new applications for the material that extends human capabilities, meet a specialized need, or improves the way we live and work. The strong linkages of STEM content brought to life in K-12 classroom by an engineering trained teacher in a technology education classroom can form the basis for new innovative learning opportunities for all students.

Our new joint program, described here, requires 4½ half years, or 9 semesters of undergraduate study. Details of the program structure and course of study are explained later in Tables 1–4. The program structure requires that students start with a traditional engineering program, including calculus, physics, and chemistry, along with engineering science courses. This sequence prepares a teacher like none other in the teaching profession. The engineering trained teacher brings to the K-12 classroom a strong preparation in the authentic application of mathematics, science, and engineering science. As the student progresses through the third and fourth years, education courses related to technology education licensure and practice in school settings are also taken. Students also develop strength in one of our traditional engineering disciplines: Chemical, Civil, Electrical and Computer, or Mechanical Engineering, which culminates in a senior capstone design experience.

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Finally, during the last few semesters, the students are placed in Professional Development Schools (PDS) where they apply their learned engineering skills in an educational context. The PDS model of teacher preparation immerses the teacher candidate in teaching practice with secondary students, a university supervisor, and K-12 cooperating teachers. This educational program is built on a strong engineering foundation and pedagogy that culminates by placing the engineering trained student in a student teaching position or internship for one semester. This program results in graduates who have earned an ABET accredited engineering degree, making them eligible for the Fundamentals of Engineering exam, and who are qualified for licensure as secondary teachers—a unique combination of skills and credentials.

BACKGROUND

Few issues evoke more passionate conversation than the education of our children. As the economy becomes increasingly global and technologically complex, our educational programs need to be strengthened to prepare today's students to be tomorrow's productive workers, citizens and leaders [1]. Recently, the Institute for Electrical and Electronics Engineers (IEEE) cited the growing influence and complexity of technology that has resulted in the increased need for a citizenry that possesses a certain level of technological literacy [2] to make informed decisions and maintain a reasonable quality of life.

Engineering education requires students to learn about how people design, make, use, maintain, and manage technology and systems through hands-on problem solving activities. The mission of this dual nationally accredited (NCATE) technology education teaching endorsement and nationally accredited (ABET) engineering science degree program at Colorado State University is to develop and educate teacher candidates who can:

- Understand why and how people design, engineer, and innovate to meet human needs and desires.
- Apply ways of thinking and doing essential to designing and problem solving, developing, making, managing, and assessing technological systems in various contexts.
- Safely use, manage, and evaluate technological systems and engineering design processes.
- Integrate the study of technology with science, mathematics and other subjects.
- Communicate technology and engineering content and processes, individually as well as in teams.
- Understand the historical and future significance of engineered designs and impacts of technological solutions on humans and the environment.
- Develop an awareness of, appreciation for, and engagement in career paths and opportunities in science, technology and engineering.

This approach is a formal method of placing engineering trained teachers' front-and-center in the K-12 classroom. Teacher candidates from this program are uniquely equipped to integrate the mathematical, scientific, technological, and engineering principles in design problems that engage students in challenging and meaningful learning experiences. In effect, many in the engineering profession want engineering content and methods to become part of the K-12 curriculum. However, in general engineers are not aware of the efforts of K-12 technology educators to include the concepts and processes of engineering in the schools. Recently, engineering societies have initiated projects to bring engineering into the K-12 schools. For example, in 1989 the Society of Automotive Engineers (SAE) developed A World in Motion, an engineering-based curriculum for teachers and students. The American Society for Mechanical Engineering (ASME) proposed legislation through state by state efforts to include and strengthen STEM education content in the schools. Most recently at the 2005 Annual Conference of the American Society for Engineering Education, a new K-12 division was approved, solely to engage in strengthening the presence of engineering content in America's schools. Thus, engineering societies are becoming key stakeholders in strengthening the engineering education pipeline.

Through academic collaborations between university-based Schools of Education and Colleges of Engineering, STEM in a contextual engineering environment in K-12 school programs can build cumulative STEM competencies in students by building on the foundation of knowledge established at each level in education, from elementary grades where students have innate curiosity about their world and how it works through middle school, high school, and beyond. Second, students learn through experiencing hands-on, open-ended, real-world problem solving experiences that are linked to the existing curriculum; using science, engineering, and technology modules/curriculum; and grouping such experiences and modules by discipline and level of difficulty. In support of this educational approach, a recent ASME position paper indicated that engineering can promote hands-on activities for students, including research-oriented classes . . . appealing to students through authentic [contextual] research projects that emphasize the use of mathematics in reporting results, and promoting engineering and technology . . .in high school. Therefore, students' working as engineers—creating, designing, analyzing, predicting, and testing solutions—are trying their educational and career goals on for size (ASME Position Statement—2002, ID #2–32, http://www.asme.org/gric/ps/2002/02–32.html, March 24, 2004).

A research informed approach

In recent years, schools have invested significant resources in training teachers to use and upgrade the integration of educational technology (computers, software and infrastructure used to deliver education) but have often ignored or failed to recognize the value in educating technologically literate students. In technology and engineering education, learning is brought to life through concrete, hands on learning experiences in laboratory environments. Through drawing, planning, applying the engineering design process, problem solving, analysis, prediction, building, and testing, students become involved in critical and creative thinking. By providing opportunities for students to explore, ask questions, and use resources of information, students learn to construct solutions that lead to more questions and additional solutions.

This design/engineering model of learning and inquiry is firmly grounded in the well researched tradition of the cognitive sciences. diSessa [5] asserts that viewing and cultivating the student as a designer/engineer in science and technology supports productive-based activities in classrooms. Activities requiring designing and constructing engage the student in the externalization of physical artifacts that present many opportunities for reflection, debugging, optimizing, and keeping the goals of the classroom activity in focus. Students engage in self-evaluation as a result of the activity structure by determining how well their designed object works. Also a design/engineering approach to teaching and learning provides ample opportunities for students to collaborate and share. Finally, diSessa explains that the type of sharing encountered in the design/engineering approach is consonant with the instructional benefits of socially-distributed instructional models.

A benefit of engaging the student as designer/engineer is the student's personal investment in the learning enterprise. Brown [6] and [5] confirm that the development of a product or expert knowledge can generate sustaining effects through personal or group pride in ownership. The development of products in the design/engineering model of instruction provides multiple opportunities for students to cooperate and share. Analogous with socially-distributed methods of classroom instruction, some design and construction activities are too large for any individual to accomplish alone. diSessa found that big design projects allow many slots for individuals with different skills and expertise to participate effectively. For example, in engineering design problems, some students may take on primary responsibility for design, others for modeling, critical analysis, or construction, and others for optimization and testing. Thus, the design/engineering model represents a method of instruction applicable to technology and engineering education classrooms that is consonant with a well researched cognitive approach to teaching learning.

In essence, educating students in the engineering design process, how technology and engineers shapes society and solve problems, and the benefits and costs of the technology engineers design for the good of humans and society opens doors for *all* students to peer into the very careers the National Science Board [3] has argued we must strengthen. Engineering education can be a primary delivery subject for delivering technological and engineering literacy for all students using an engineering design approach to authentic analytical problem solving. This leads us into the core relationship technology shares with science, engineering and mathematics.

Contextually situated STEM content

Science, technology, engineering and mathematics tenets naturally intertwine, each supporting and complementing the others. It is the learning synergy derived from engaging students in engineering design activities that brings the STEM content to life in K-12 classrooms. Pea and Gomez [7] argue that STEM instruction must focus on understanding and supporting learning in entirely new ways. Pea and Gomez assert that the model of most educational settings is learning-before-doing. They maintain that attention in STEM classrooms must be focused on learning-in-doing. Learning-in-doing is a model in which learners are increasingly involved in the authentic practice of engineering design communities through learning conversations and activities that include and extend past educators and peers to expert practitioners in the engineering field that support work based learning. Learning-in-doing engineering design activities bring together the logical combination of STEM.

The four STEM disciplines should not be taught in isolation in a school curriculum, but be interdisciplinary reinforced, and continually cross-referenced, as part of a dynamic triangle that ultimately researches, designs, and creates the way we live, work, and play. Therefore it only makes solid academic and professional sense to prepare teachers who are highly qualified to deliver this integrated content in a K-12 setting [8]. This interdisciplinary STEM concept is a powerful, yet critical, void in most public education.

Currently there are several approaches taken to affect this desired integration and teacher preparation. First, engineering communities and professional organizations have cooperated with K-12 education to develop curriculum, either for the classroom or summer bridge programs that provide engineering experiences for students. Second, some engineering schools have participated in outreach programs where engineers (sometimes graduate students in engineering) team with K-12 teachers in the classroom. Third, programs have been developed to enhance in-service training for teachers through professional develop programs centered on engineering design knowledge and activities and fourth, hybrid pre-service teacher education programs have recently been developed that include some engineering coursework yet stop short of requiring a full engineering degree. Details about each of these approaches can be found in the literature, e.g. [9–11], especially in this special issue of the *IJEE*. Next, we describe a fifth and more direct approach: developing engineers–teachers through a joint undergraduate program.

NEW PROGRAM DESIGN

Education licensure requirements and considerations

The engineering education program at Colorado State University is designed and delivered as a developmental progression of coursework and field experiences. Through their participation in this program, teacher candidates acquire the content relevant to the teaching area (engineering education) as well the pedagogy essential to effective teaching and learning. The program, upon completion, culminates in the awarding of the engineering science degree as well as the institution's recommendation to the Colorado Department of Education for teacher licensure in technology education. Thus, the program is a composite of two academic units: the College of Engineering and the School of Education.

The program of study comprises four discrete phases of study and is reinforced throughout by a philosophical and programmatic core of learning based on national, state, and institutional standards; by extensive and intensive partnerships between and within the university and local school communities; and by maximizing the experiential learning opportunities for candidates. The successful completer will have participated in a minimum of 870 hours of supervised fieldwork in K-12 schools at the conclusion of the program.

To ensure strong engineering discipline preparation, Colorado law mandates that teacher education candidates complete programs only in approved majors. Approval of majors acceptable for teacher education programs resides not only with the university but also with two state educational and regulatory agencies: the Colorado Department of Education (CDE) and the Colorado Commission on Higher Education (CCHE). CDE reviews the content of the major to ensure that completers are able to demonstrate proficiency in all standards addressing what a teacher needs to know and do in their specific discipline (i.e. engineering science). CDE then recommends action to its governing board, the State Board of Education. Following the State Board of Education's approval, the program is reviewed by the CCHE to ensure that it meets all programmatic performance measures (e.g. candidates are admitted into this area through a rigorous and prescribed process; candidates' content preparation is assessed regularly; the program maintains prominent benchmarks of success, etc.).

CCHE also ensures that all majors leading to teacher licensure are delivered within a specific and limited number of semester credits. In Colorado, CCHE has established that majors culminating in both the degree and teacher licensing recommendation may not exceed 126 credits. One obstacle in the approval of this engineering education program was this credit limitation. At the time that this engineering education proposal was considered, there were no teacher education programs that exceeded 126 semester credits. Yet, the engineering education program, in order to be in compliance with all accrediting bodies, necessitated a total of 136 credits of study. CCHE was petitioned for a waiver of its limitation on credits and ultimately granted approval to this major leading to teacher licensure. This program remains as the only major leading to teacher licensure in Colorado that exceeds the 126 credit limitation.

ABET-engineering requirements

The Accreditation Board for Engineering and Technology (ABET) accredits engineering curricula in the United States. In the year 2000 ABET promulgated a new set of criteria comprising eleven learning outcomes. This shift from a proscriptive list of requirements to an outcome-based approach coincided with a greater emphasis on assessment as a means for program improvement. These new criteria were designed to encourage engineering programs to develop their own unique missions—this encourages greater flexibility in curriculum design. With this new environment of flexibility comes a greater opportunity to develop new engineering programs—such as our new joint engineering-education degree program.

Curriculum

The engineering and education faculty have developed a new curriculum that satisfies both the requirements for an ABET accredited engineering degree and the NCATE requirements for licensure in technology education at the same time. The result is graduates who are engineers qualified to teach in the K-12 educational system.

The curriculum for our joint program consists of four major components. First, as with many universities, there is a component of the curriculum often referred to as the general education requirement, or sometimes as the liberal education portion, shown in Table 1. These courses are meant to broaden the mindset of students, helping them put meaning to their technological education—creating a greater context for their profession. The curriculum requirements in this area comprise 49 credits covering topics from mathematics and science to history, arts and humanities.

The engineering portion of the curriculum comprises the second and third components: engineering science core courses and engineering science technical electives shown in Table 2 and

Table 1. General education requirements

Course topic	Credits
Composition	3
Calc I and II	8
Speech	3
Statistics	3
Chemistry I	5
Physics I and II	10
Arts and Humanities	3
Social/Behavioral Science	3
Historical Perspectives	3
Global & Cultural Perspectives	3
U.S. Public Values/Institutions	3
Health and Wellness	2

Table 2. Engineering science core

Course title	Credits
Engineering Mechanics	3
Fluid Mechanics	4
Mechanics of Solids	3
Structural Analysis	3
Intro. to Electrical Engineering	3
Calc III	4
Differential Equations	4
Intro. to Engineering Design	3
Mechatronics & Measurement Systems	4
Intro to Engineering Materials	4
Thermodynamics	3

Table 3. Engineering science electives

Course title	Credits
Civil Engineering Principles I & II	6
Civil Engineering Design I & II	6
or	
Intro to Manufacturing Processes	3
Mechanical Engineering Problem Solving	3
Mechanical Engineering Design Practicum I & II	8
or	
Electrical Engineering Fundamentals	3
Circuit Theory	3
Electrical Engineering Design I & II	6
Technical Electives	1–3

Table 4. Professional education requirements

Course topics	Credits
Schooling in the U.S.	3
Education Technology & Assessment	3
Literacy and the Learner	3
Instruction I & II	7
Practicum—Instruction I & II	2
Assessment of Learning	1
Methods/Materials in Technical Education	3
Student Teaching—Secondary	11
Seminar—Professional Relations	1

Table 3. In the engineering science core sequence, the traditional topics of mechanics, thermodynamics, materials, etc. are included. These topics form the basis for most engineering curricula and are essential for the understanding and application of engineering design principles. Students will be exposed to the breadth of engineering—this also forms the foundation for any engineering-related K-12 curricula that the graduates may develop.

Engineering electives make up the third component. In this portion of the curriculum, students first take a first-year sequence of introduction to engineering courses. Depending on the desired emphasis, students can elect to take these courses from tracks in Civil, Electrical and Computer, or Mechanical engineering. During the senior year a second sequence is taken that provides a capstone design experience for the students within the selected emphasis area of study. Students work in teams to conceive and implement fairly comprehensive design projects. Colorado State University has a long tradition of combining theoretical and practical knowledge so the senior design projects span two semesters and typically result in some design artifact. For example, students have recently designed and build race cars, human powered vehicles, and fire-fighting robots. This is the sequence that will set these students apart from teachers who do not receive the full training provided by an engineering curriculum. By synthesizing the engineering curriculum through the capstone experiences, these future teachers will have a deeper understanding of the engineering design process—the heart of the engineering profession.

To complete the curriculum, a set of professional education courses comprises the fourth curricular component as shown in Table 4.

These course topics provide students with the necessary pedagogy, knowledge, skills, and dispositions for gaining licensure/certification to teach technology education at grades 6–8 and high school level.

IMPLEMENTATION AND ASSESSMENT

The engineering science degree major with a concentration in engineering education was approved for teacher licensure in June 2005. As discussed earlier, approval was required by both CDE and CCHE. During the Fall semester of 2005 the degree concentration in engineering education within the engineering science degree program was being finalized on campus through the curriculum approval process. The Spring 2006 semester was the first semester that students were able to enter the program. Plans within the College of Engineering and School of Education were put in place for a phase recruitment process with a target goal of 11 students to be admitted to the program within the first year. This target was established so no impact on course enrollments and PDS field placements would be felt or additional resources required across the engineering science core or engineering science electives that come from other engineering majors.

Early results of students entering the program show that the engineering teacher candidates are very different from past traditional technology teacher education students. All are at or near the top of their engineering class with grade point averages over 3.85, highly qualified in science and mathematics, and over 70 per cent are female. During the spring semester of 2006 the first engineering education students admitted to the program were enrolled in the early phases of classroom field experience. Assessment from early field experience practice indicates that the engineering trained teacher candidates engage students well in both theoretical and application type lessons. For example, one student was observed delivering a lesson on communication infrastructure required in community planning. The engineering teacher candidate was discussing multiple types of communication and signal transmission modes, i.e. wireless, cable, fiber optic, when a heated debate ensued with the eighth grade class about Internet over telephone line and modem. The engineering trained teacher candidate was observed diagramming the voice signal and digital signal being carried over the telephone line. The students debated their misconception that when on a telephone modem Internet connection a voice signal could not be carried. The teacher candidate went on to explain the principle of a signal filter that could be used to simultaneously enable voice and modem Internet to be carried simultaneously.

Program achievement will continue to be measure by program enrollment, candidate success on School of Education field placement assessments and engineering science candidate performance measures in coursework, and capstone design experiences. The program goal of maintaining a pipeline of 11 students in the engineering education concentration has required the program advisors to build a recruitment Website and new program recruitment materials. In addition, recruitment trips are planned at key high school student professional association conventions such as Technology Student Association (TSA) where students and parents can become aware and informed about this new academic and career opportunity.

DISCUSSION

Comparison with other approaches

Colorado State University's joint engineering–education curriculum develops teachers with a very different background from most current secondary technology education teachers. Our graduates will possess an accredited engineering degree that gives them the knowledge and skills of an engineer that can be used to further enhance the quality, focus, rigor, and relevance of secondary school technology education programs. Most current efforts at integrating engineering education into the secondary experience are either attempts to provide some skill to technology education teachers or the development of engineering-based curricular materials and experiences that may be presented by technology education teachers or by visiting engineers. CSU graduates will have a deeper understanding of the integration of STEM content, engineering science and the engineering design process than can be developed as an add-on to other degree programs.

Therefore, engineering education as the pre-service academic preparation for the technology education teaching endorsement in Colorado will add a dynamic element to our K-12 schools. The product is a highly qualified teacher versed in the sciences, technology, engineering, and mathematics who would close the subject and learning relevance gap through authentic application, exploration, design, and inquiry in Colorado classrooms.

SUMMARY

We ask you to imagine a world, in which workers are technically competent but technologically illiterate. A world in which a person can 'fix' a hardware problem with a personal computer but may not be able to evaluate the risks, benefits or tradeoffs associated with understanding if a gas–electric hybrid engine is a good investment, or if it would be better for the environment than a traditional internal combustion engine [12]. Our citizens, our economy, our environment, our democracy are all dependent upon a certain level of 'technological understanding'. How can a person reasonably vote in an election on issues such as 'Star Wars Defense System', 'human cloning', 'fuel cells', 'flexible transistors', 'robots', 'nanotechnology', etc. without having general background knowledge in engineering and technology? Unless action is taken, we are at a crossroads where citizens can be trained to do a skilled job but not understand the benefits or consequences of using a present or future technology rationally and responsibly. In reality, few students are leaving schools in Colorado today with adequate literacy in engineering and technology to become the informed citizens of tomorrow and to make informed educational choices for their future.

The study of engineering in education helps create a citizenry that is highly literate, disciplined, capable of thinking critically and creatively, knowledgeable about a range of cultures, and able to participate actively in discussions about new discoveries and choices. Students are leaving our K-12 educational systems with an adequate understanding of educational technology (computers), but dangerously lacking in the skills and abilities to make informed decisions on present and future engineering and technological issues.

Colorado State University is taking a proactive leadership role in initiating systemic change that will positively influence the future of all K-12 education. This new joint degree program is built on new partnerships across traditional academic and disciplinary lines to innovate, cooperate and prepare highly qualified teachers.

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Thomas J. Siller is an Associate Professor in Civil Engineering and the Associate Dean for Academic Affairs for the College of Engineering at Colorado State University. As the Associate Dean, he is also responsible for the Engineering Science program where the new joint education degree resides. His research focuses on curricular reform efforts in engineering education and he currently is an Affiliated Scholar for the National Academy of Engineering's Center for the Advancement of Scholarship on Engineering Education. He also serves on the national curriculum committee for the American Society of Civil Engineers Body of Knowledge effort.

Michael A. De Miranda is an Associate Professor of Engineering Education in the School of Education at Colorado State University. Michael's current responsibilities are to provide leadership in the development of young STEM educators for the future of the engineering profession and conduct research on learning, cognition, and instruction in engineering and technology education. His research is focused on the study of cognitive process and complex classroom interventions associated with achieving scientific and technological literacy. He currently serves as President of the Council on Technology Teacher Education (2004–2007) and member of the American Society for Engineering Education (ASEE) K-12 division.

David C. Whaley, formerly of Colorado State University, is now Associate Dean for Teacher Education at Iowa State University. While at Colorado State University, Dr. Whaley administered the educational licensing program which includes 15 initial endorsement areas and four advanced areas. Dr. Whaley also taught courses in educational methodology and in school law. His research agenda focuses primarily on educational policy implementation.