Innovative and Creative K-12 Engineering Strategies: Implications of Pre-service Teacher Survey

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Abstract

This study sought to find student perceptions of how the engineering design process is learned and applied by pre-service teachers at the University of Georgia. The course description read "demonstration and hands-on learning, including problem solving, designing, construction and testing of prototypes, and activities that increase aesthetic, psychomotor, and cognitive development", according to the UGA bulletin. A total of 12 students participated in this qualitative study. The four questions asked were about course expectation, outstanding experiences, definition of engineering process, and relevance of the course to future career plans. Six themes were drawn from student responses.

Introduction

Many attempts have been made to provide a K-12 engineering experience to students through stressing the importance of design in both identification and solving of problems (Katehi, Pearson, & Feder, 2009; Kemsley, 2010). As English (2008) said, "Given the increasing importance of engineering and its allied fields in shaping our lives, it is imperative that we foster in students an interest and drive to participate in engineering from a young age" (pp. 189). Materials for student learning in K-12 engineering have been developed through private and government channels such as *Project Lead The Way, EngineeringbyDesign and Probase* activities. State governments such as Ohio, Massachusetts and New York have provided resources and established avenues to access K-12 engineering related materials. As noted above, most of the initiatives at K-12 engineering have been "add on" activities geared towards in-service teachers. In their discussion about in-service programs, Custer and Daugherty (2009) observed that teachers were engaged in exciting activities, worked with well-developed curricular materials, and interacted with one another in constructive and positive ways. They further argued that the primary focus of in-service workshops should be tools usage, techniques, processes, and technical details and not teaching methods or learning processes. In his view, Hill (2004) had observed that significant commitment will be required if members of the profession were to upgrade analytical knowledge and skills to meet K-12 engineering teaching preparation. The in-service programs do not seem to provide time for a significant commitment.

On the other hand, pre-service initiatives for K-12 engineering are few, sparse and diverse across the United States. For example, "three K-12 engineering models" currently practiced at highly ranked research universities include a purely engineering undergraduate degree as the case is for Colorado State University; a technology education curriculum with infusion of engineering basics as in Utah State University; and a technology education curriculum within Career and Technical Education at the University of Georgia. Although this is a rich mix of curriculum models for teacher preparation, its diverse approach does not promote a common cause for the discipline and the graduates are ill-equipped for knowledge and skill transferability for careers or graduate school. A need exists to find a suitable platform on which the pre-service teacher can fully build upon. Though the study was conducted with elementary education pre-service teachers, authors intentionally include general K-12 engineering education because in many cases, teacher preparation programs do not separate the elementary from the high school engineering and technology teacher preparation. Authors set out to find what the literature had on K-12 engineering and compare it with pre-service teacher experience.

Literature Review

Nature of K-12 Engineering Education

K-12 engineering is different from collegiate engineering education and also from science and mathematics. It strives to integrate concepts mainly from math and science to establish a method or process of problem solving techniques. Jeffers, Safferman and Safferman (2004) viewed engineering as a natural phenomenon. Genalo, Brining, and Adams (2000) stated, "Young children are inherently active with strong impulses to investigate to share with others what they have found out, to construct things, and to create" (Jeffers, Safferman, & Safferman, 2004, pp. 95). That is, K-12 students naturally have a strong interest in the technologies they experience in their daily lives (Jeffers, Safferman, & Safferman, 2004). Katehi, Pearson and Feder (2009) discussed five benefits that K-12 engineering education can provide: (a) cultivating learning and accomplishment in science and math; (b) allowing enhanced comprehension of engineering and engineers' work; (c) increasing knowledge and ability in engineering design; (d) providing career interest in the engineering field; and (e) strengthening technological literacy. As a way to help visualize the correlativity and strengths of K-12 engineering with other subject matter at the secondary level, Katehi et. al. illustrated the *beads-and-threads model* by reviewing 34 curriculum programs' contents. This model shows that the intertwined threads of the key concepts and elementary skills in science, math and technology utilized in engineering design run through the beads of specific curriculum activities such as robotics and clean energy technology (Roger, Wendell, & Foster, 2010).

Innovative K-12 Engineering Education

The National Science Board (2007) stated that innovation in K-12 engineering needs to focus on the changing global context of engineering, the public perception of engineering, and retention of students who are interested in engineering. The Board recommended an integrated STEM education approach because its four areas are intertwined and vital towards problem solving. Technology is a tool to enable the use of science and math to create solutions to existing and future problems. Mathematics enables the building of models for study and prediction. Science provides critical information and limits on natural possibilities. Engineering uses technological tools to develop and study models and natural limits to create solutions that benefit humans and the environment. All in all, a mathematics silo by itself is limited to its problem solving capability; a science silo studies nature and on its own cannot solve problems; a technology silo is a collection of tools and cannot solve problems either. However, when the silos are integrated they become a rich resource vault that can be systematically used through engineering by tapping into laws of science, use of mathematical constructs and models, and application of technological techniques to explore solutions to problems.

For implementing interconnected STEM education, curriculum and test development, assessments, and professional development for engineering teachers through related research would be necessary (NSB, 2007). NSB also insisted that K-12 engineering teachers' competence should be ensured in terms of sufficient knowledge and skills to teach engineering through certificate or licensing.

Pre-service Teacher Education for K-12 Engineering

Moreno (1999) stated, "Teachers' pre-service education is frequently distinguished from the professional development of practicing teachers, known as in-service education" (p. 573). Pre-service (undergraduate) teacher education programs do not necessarily require hard science or mathematics course work, particularly for future elementary-level teachers. As a result, many elementary school teachers graduate without even a rudimentary education in science and mathematics (Moreno, 1999). An innovative K-12 Engineering program will require significant changes to the teacher education curriculum for those intending to pursue the discipline. They will need to understand the necessary mathematics and science concepts and how they contribute, integrate, and tie together to get solutions to problems. Fantz, De Miranda and Siller (2010) discuss in detail on how to best equip an engineering and technology teacher. They propose a curriculum that echoes substantial math and science. The engineering dean at Ohio Northern University, Eric Baumgartner, has proposed a new engineering education major geared toward high school engineering and technology teachers that will start in fall 2011 (email communication to ASEE ETD listserv March 8, 2011). The degree program is strong in math and science.

An undergraduate program in general engineering may be the best option for the K-12 engineering teacher. The Naval Academy defines its general engineering program as an interdisciplinary, broad focused major. Its initial course work includes mechanics, materials, fluid dynamics, and thermodynamics which are similar to courses other engineers take. The relatively large number of electives in general engineering permits a student to seek some depth in one area of interest in engineering (USNA, accessed 2012). Even though there is no data supporting the argument that a general engineering program leads to a competent K-12 engineering teacher, the shear engagement in content and experience gained through the course work and team work lends itself to developing a knowledgeable and skillful individual. This preparation is vital for pre-service high school teachers who become potentially STEM integrators to problem solving. The pre-service elementary and middle school teachers may benefit from the general engineering program, but the rigor is not necessary. It is common sense that one cannot deliver what one does not have, without confidence, the K-12 teacher will be left to wander in the jungle along with his or her students. Such an outcome is not the best practice in a profession.

Implications from the Students Survey

The purpose of this survey was to understand how the engineering design process is learned and applied by the pre-service teachers. They took the course *ETES 2320: Creative Activities for Teachers* in the fall 2010 semester at the University of Georgia. This course is described as providing "demonstration and hands-on learning, including problem solving, designing, construction, and testing of prototypes, and activities that increase aesthetic, psychomotor, and cognitive development," according to the UGA bulletin. The course is aimed at elementary education pre-service teachers.

Participants

A total of 12 students (two sophomores and 10 juniors) participated in the study. Of the 12 participants, 11 were female and one was male. All participants identified themselves as Caucasian. All participants stated that this was a required course.

Method

A need to determine student perception of engineering design was voiced in the department to establish whether or not intended course objectives were being met with particular interest in student gain in content and future use. Permission was sought from the Institutional Review Board to conduct the study. Once IRB approved the study, authors developed a survey instrument to guide collection of information. The instrument went through three iterations and was piloted on two separate occasions with two different groups to ascertain clarity and reliability. After it was established that the instrument was reliable, permission to administer the study was sought from the course instructor. With permission granted, students were informed of the survey and their consent was sought prior to participating in the study. Survey questions were: (1) what were your expectations when you signed up for the ETES 2320: Creative Activities for Teachers Course? (2) describe your outstanding experience in the ETES 2320: Creative Activities for Teachers with respect to content, learning activities, and preparation for your career. (3) At this point in your learning, please define engineering process in your own words. (4) Reflecting from your course, how would you apply the experience to your future teaching? Each participant was asked to complete the survey and authors were on hand to respond to any questions asked. Authors compiled survey information, triangulated it and assembled emerging themes.

Summary of Survey Answers

In regard to course expectations, students expected to learn creative teaching methods to use as future educators. Several of the students also revealed a misunderstanding of pre-service K-12 engineering teacher education, relating the course to specific subjects such as art, crafts, computer and technology. Students' outstanding experiences involved having helpful learning content, which proved to be fun, interesting and practical. They also found the hands-on learning activities to be beneficial, interesting, and useful, recognizing the importance of practical learning. Students defined the engineering process as a problem solving process, involving a series of steps including exploring, planning and creating. They stated that they would apply their learning from this course by using similar activities in their future classrooms, using hands-on learning opportunities for K-12 engineering classes.

More detail

Many students had the expectation to learn how to teach their future students in creative ways through the ETES 2320 course. For example, "My expectation was to learn how to create engaging activities to use in my future classroom and to enhance the students' experience in learning new material"; "I expected to learn about different creative ways to teach beyond lectures and the textbook". These expectations were in accord with the goal of the ETES 2302 class. However, some students thought the course was related to specific subjects such as art, crafts, computer or technology. Therefore, a more detailed and engineering-focused course description is needed for students to avoid misunderstanding in pre-service K-12 engineering teacher education.

Most students answered that the content of this course was helpful in preparing them for their future teaching careers. For example, "I have learned how to do many exercises and have benefitted from seeing my peers projects as well"; "The content has been fairly interesting; we have mainly learned about the changing technological world and how society is changing". These responses clearly show that students' learning needs should be investigated and reflected in the curriculum development process for pre-service engineering teacher education.

Students' recognized clearly the importance of practical learning activities in this course. Various class activities can boost K-12 students' learning motivation by providing fun and new learning experiences that differ from a general lecture style class. Hands-on activities in an engineering course are beneficial for K-12 students to develop their engineering-related skills (Jeffers, Safferman & Safferman, 2004). Therefore, a course for pre-service teachers containing various and creative learning activities that can be used in their future teaching is necessary in K-12 engineering education.

Course contents and related activities that meet students' needs can be achieved by performing classroom assessment that allows teachers to gain more insight about their students' learning progress and responses to teaching methods through feedback. According to Angelo & Cross (1993), the more a teacher recognizes how students learn, the better he/she is able to plan learning activities and systemize teaching processes. Teachers can modify their teaching approaches with students' feedback to ensure student-centered learning. This approach is important to educators of pre-service teacher preparation in higher education as well as future K-12 engineering teachers. When pre-service teachers experience and acquire student-centered teaching skills, they are more likely to apply the techniques in their work.

The students mainly viewed the engineering process as steps of creating solutions for problems in creative ways. For example, "Engineering processing is the ability to solve a problem through a detailed thought process, which results in an effective and useful solution"; "The engineering process, in short, is the planning of an idea or project, making the planned item come to life, and implementing it into everyday life"; "The engineering process is a series of steps used to prepare for and execute tasks"; "It is about thinking of a creative way to solve a problem, carrying out that plan and then modifying or improving it".

K-12 engineering education's first principle stresses the importance of engineering design in both the identification and solving of problems (Katehi, Pearson & Feder, 2009); an iterative process that recognizes that real-world problems have multiple solutions subject to constraints. A curriculum built on engineering design challenges provides a context for the learning of mathematical, scientific and technological concepts, while stimulating higher order, and critical and creative thinking. Future engineers will need strong analytical skills, practical ingenuity, creativity, communication skills, and an understanding of the principles of leadership, business and management, and high ethical standards and professionalism (NAE, 2004). In the primary and secondary level curriculum, engineering problems could be incorporated to engage students in problem solving with creative and innovative methods, and to encourage group work that allows students to learn collaboration and communication to solve complex real-world problems (English, 2008; Bellanca & Brandt, 2010).

Pre-service teachers answered that they would use various hands-on learned activities in their future K-12 engineering classes. For example, "I can take ideas and projects from this class and amend them or alter them to use in my classroom. It has given me awesome project ideas to use with certain lessons to ensure that students have hands-on experiences that promote learning." "I have learned to creatively solve problems in my classroom regarding activities and lesson plans. I would be able to modify and improve on these activities or lesson plans for the future." According to Sawyer (2004), creative teaching means disciplined improvisation because it takes place within expansive structures and frameworks. Skilled teachers apply usual activities to their teaching processes more than beginning teachers; however, they can motivate and incorporate these accustomed activities in creative and improvisational ways.

Conclusion

Participants from the study projected benefits for taking the course and being exposed to the engineering design process. The six themes that emerged were evidence of their agreement in new found knowledge and skills. Many participants expressed their appreciation of hands-on learning experience. Therefore, from their participation in semester long class activities, they are equipped with creative methods of teaching K-12 engineering at the elementary level. In addition, the creativity opens gates to various approaches to problem solving techniques so they can guide their future students to explore multiple ways to solve problems using the engineering approach.

Although many in-service workshops and materials are availed for teachers to use, the meaningful investment seems to lie in the formulation of effective curriculum at the pre-service level since inculcating of the knowledge and skills take a while to cement. This preparation will enhance teachers' confidence in integrating both math and science while using technological techniques towards systematic solution finding and not wandering in many directions.

The development of creativity, pursuit of solutions to real-world problems, generation of innovative ideas, and ability to make connections between previously unconnected ideas are all necessary for the development of engineering thinking and are tenets of curriculum development in gifted education. These activities need to begin in elementary school to have the greatest effect on career decisions (Magnuson & Starr, 2000). Survey results could be used as information for creating innovative pre-service teacher education at the college level.

Pre-service teachers who participate in such a program of study would leave the course with an essential set of skills. They would be prepared to examine the local economy of their future class, based on geographic location. These undergraduates would also be aware of how and where to access resources to construct hands-on activities. Finally, they would have turnkey examples to use within their future classrooms.

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