A Model to Promote the Study of Engineering through a Capstone Course for Pre Service Secondary Science and Mathematics Teachers[1]

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ABSTRACT

In today's world of global economic competition, the US is trying to maintain its competitive edge among industrial nations by training a sufficient number of engineers. However, the number of trained individuals graduating from US colleges does not meet our current and projected needs. In addition, the number of females and minority graduates with engineering degrees is unacceptably low and the attrition rate in engineering programs is unacceptably high.

The causes include (i) the inadequate preparation of our high school graduates, (ii) unfavorable attitudes toward engineering and other science based careers, (iii) the absence of continuity in the transition from high school to college, and (iv) teacher-centered teaching methods in engineering programs. Some additional preparation for secondary science and mathematics teachers as well as high school courses that are more friendly to engineering and technology would address the first three above perceived causes. The use of more student-directed instruction might address the fourth perceived cause. To this end, it is suggested that colleges of engineering and education collaborate to develop capstone courses for secondary science and mathematics pre-service and in-service teachers. The literature indicates that engineering capstone courses that integrate engineering principles with other disciplines have been developed at some universities. However, to our knowledge, no model has been proposed to design capstone engineering courses that train pre-service and in-service secondary science and mathematics teachers in engineering principles, practice, design, and problem solving skills.

I. INTRODUCTION

In a recent NSF report on undergraduate education [1], the following challenges were identified:

1) Changing World and Economy: With the end of the cold war, there is less concern with science, mathematics, engineering and technology (SME&T). Yet, the challenges of a global economy make it imperative that we have a well-trained work force to compete with other industrialized nations.
2) Student Preparation: Students entering college are often inadequately prepared for SME&T education.

The report emphasized the importance of early student motivation and preparation in overcoming these difficulties. Most current teacher training programs in the US do not provide the motivation, attitudes or adequate training to high school science and mathematics teachers to enable them to prepare their students to be receptive to careers in engineering and technology. In the important science and mathematics prerequisites for engineering and technology, the US does not compare favorably with other industrialized countries [2]. Unless such preparation is provided, the US will lack the technical work force that our industry needs to compete with other industrialized nations [3]. Furthermore, few women and minority students choose engineering/technology careers [4], [5].

To meet the goal of increasing the number of high school graduates who pursue careers in engineering and technology, especially the under-served, new engineering capstone courses must address the following questions:

1. How can we train secondary science and mathematics teachers so that they have both the motivation and

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knowledge to include engineering content knowledge and problem solving skills in their classes?

2. How can we prepare secondary high school and mathematics teachers with the skills needed to revise existing mathematics and science courses and to develop new ones with more engineering principles and design?

3. What additional teaching models and methods can be incorporated into instruction to help reduce attrition rates of engineering students?

For the convenience of the readers, we now list the acronyms used throughout this paper:

CLM: constructivist learning model.
NSES: National Science Education Standards.
SME&T: science, mathematics, engineering and technology.
STS: Science Technology and Society.

II. THE NEW CAPSTONE COURSE

Starting in the fall of 1998, a new capstone course will be required for graduating secondary science and mathematics pre service teachers during their senior year and prior to student teaching. With some modification, it will also be available for graduate credit for returning science and mathematics teachers working on graduate degrees.

Faculty and administration in both the College of Education and the College of Engineering enthusiastically supported the new course. The College of Engineering welcomed it as an opportunity to expose high school teachers or future teachers to engineering as a profession and as a boost to their FTE. The College of Education support came from the science and mathematics faculty in the Department of Curriculum and Instruction. The six science and mathematics faculty agreed that such a capstone course was needed for science and mathematics teachers. Graduates of the College of Education must have two capstone courses and both can be outside the college. With no infringement on territory and no loss of FTE, the rest of the Curriculum and Instruction faculty had no objection to a required capstone in the College of Engineering.

The new course will introduce the pre-service and in-service teachers to engineering problem solving through specific practical applications. It will include the following: (1) projects to be completed by teams of students; (2) lectures by the instructors and guest lecturers; (3) activities performed by practicing engineers and students, and (4) the related ethical, social and environmental issues within the rubric of Science, Technology and Society (STS). It should also emphasize science literacy and inquiry learning, the two main goals suggested by the recent National Science Education Standards (NSES) [6]. Teaching models that incorporate the constructivist learning model (CLM) [7] and the five domains of the STS teaching method [8] will also be used in the course. There is still some confusion among science educators and perhaps scientists as well, concerning science literacy and inquiry learning (the two national goals of the NSES) and the preferred learning and teaching models in science education, the CLM and STS. More specifics as to what they are and how they will be implemented in the capstone course will be further elaborated on in this section of the paper.

II.1 Science Literacy, Inquiry Learning, STS and the CLM

The critical question concerning science literacy is "what the scientifically literate person should know, value and do as a citizen" [7]. In his best seller, *Cultural Literacy* [10], Hirsch attempted to outline common cultural knowledge he thought every American should learn in school. A book titled *Science Matters* [9] attempted the same for science literacy. *Science Matters* specified what the science literate person should know including everything from DNA to entropy to the periodic table. Even though the essential knowledge needed for science literacy is rarely agreed upon by educators and scientists, most seem to agree that science teachers' should orient school science programs toward the knowledge, values and skills required in scientific and technological careers. The question, is how to do so and still promote science literacy in the more than 90 per cent of students who will never pursue careers in science, mathematics and engineering. A possible solution is an instructional program that uses the constructivist learning model (CLM) [11] and a Science, Technology and Society (STS) [12] teaching approach. The CLM and STS have been suggested as the best way to interest the majority of our students in science and technology both in and out of school [7], [11], [13].

Moreover, if science literacy is to really be achieved in at least a majority of our citizens, what might be more important is a science program that stresses all five domains of science teaching (Concepts, Processes, Connections and Applications, Creativity and Attitude) within a STS context. STS may be thought of as the teaching and learning of science in the context of human experience. STS means focusing on real world problems that have science and technology components from the student's perspective, instead of starting with concepts and processes. This allows students to investigate, analyze and apply concepts and processes to real situations [13]. Such a program can still include the essential concepts and processes associated with the traditional science disciplines; e. g., earth science, biology, chemistry and physics; while emphasizing the connections and applications of science to students' lives. These connections and applications are what lead to science literacy, the main goal of the NSES.

Among science educators, the recently introduced NSES seem to offer the current best hope for addressing the need for science literacy and inquiry learning within the STS context in our students. The (NSES) were primarily designed to guide the United States toward a scientifically literate society. According to the NSES, science literacy is important because (a) an understanding of science provides personal fulfillment and excitement, and (b) Americans are confronted increasingly with questions in their lives that require scientific information and scientific ways of thinking for informed decision making. The NSES defines science literacy in the Perspectives and Terms section of the Standards (page 22) as follows:
"Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs and economic productivity."

It is also worth mentioning that the NSES includes technology literacy as an essential part of science literacy. One of the eight content standards for grades K-12 is Science and Technology. This standard (Content Standard E) for high school states that "as a result of activities in grades 9-12, all students should develop abilities in technological design and an understanding about science and technology" (page 190). A key word in the statement is *activities*. This is where design, the CLM, and STS can be integrated. If teachers choose societal problems that require knowledge of science and technology for their solutions and require inquiry by students in concrete activities, then students can learn to become better problem solvers by learning to apply engineering design principles. A principle part of the capstone course will be to train teachers in the way engineers go about problem solving. The teachers can then introduce these methods into the activities in their own science and mathematics classes. This is closely tied to the CLM. The CLM depends on students doing activities and projects that provide common experiences. It is felt that the many misconceptions that students have in science classes can only be overcome with common experiences in which students are allowed to discuss what they observe and develop concepts that explain and give personal meaning to those observations. The teacher's role is to provide the experiences needed for students to inquire and reach an understanding of new concepts as well as overcome misconceptions held from prior "learning". As students make observations, pose questions, examine what is already known, plan experiments, use tools to gather, analyze and interpret data; propose answers, explanations and predictions and communicate results; they are using inquiry [6]. The critical role of the teacher in using the CLM is to provide appropriate activities and clarify misinformation to help students construct the correct explanations.

II.2 Specific Engineering Applications

The course will further the goal of teaching students to become problem solvers by emphasizing an introduction to the practice of engineering rather than its theory. The course will set up problems, present simplified solutions, and avoid complex theoretical developments. Further explanation of how the projects will be set up as well as examples of some of the projects are provided below.

1) Projects to be completed by teams of students:

The students in the class will be organized into teams. Each team will complete a set of projects that simulate the working environment [14] of practicing engineers. The project will investigate the concepts involved in a simplified version of a practical engineering problem that retains the essential aspects encountered in engineering practice but avoids complex theory. The students will be provided with the skills necessary to develop simple projects for their high school students using popular magazines such as Popular Electronics and adding the engineering practice flavor that these magazines rarely convey. The projects will emphasize the following:

(i) *Problem solving skills:* Each project will be presented as a problem for which each team of students must find a solution. Students will be encouraged to address each problem with an open mind and positive attitude to encourage innovative practical solutions.
(ii) *Oral and written communication:* At the completion of a project, each group will present its results to the class.
(iii) *Economic or business analysis:* An analysis of the cost and marketability of the product of each project will be required where applicable.
(iv) *Ethics and Professionalism:* Whenever possible, ethical and professional issues related to the project will be raised and discussed collectively in class.
(v) *Social and Environmental Issues:* Projects that involve the social and environmental impact of engineering will be used for group discussions of these issues.

Examples of projects to be completed by the students are:

a) *Lie Detector:* A lie detector will be constructed by measuring changes in skin resistance for the subject. Additional indicators are pulse rate and breathing rate but those will not be considered for simplicity even though a biology teacher might want to infuse them into an existing curriculum in biology. Questions to be addressed include: Is there a market for this product? What are the ethical issues involved with the lie detector?

b) *Temperature Control:* A pulse with modulated temperature control system will be designed as an alternative to the standard home heating system. Questions to be addressed include: Is this product sufficiently competitive with the standard home heating system? What is the maintenance and operation cost of the system?

c) *Bridge and Building Design:* Students will be introduced to different bridge types and their uses and then given building kits to construct their own bridges. Each bridge will be loaded to determine the bridge with the highest strength-to-weight ratio. Students will also be shown slides on bridge performance during earthquakes and will tour the Bridge structures Lab, the largest facility of its type in the United States. A small shake table will be used to demonstrate the performance of a frame under earthquakes.

d) *Highway Project Design:* Students will design a horizontal and vertical alignment of a two-lane rural highway using Nevada Department of Transportation standards. Student teams will produce plan and profile views, cross sections and compute earthwork volumes. The students will be allowed to keep the plans they work from and the software they use.

e) *Surface Water Treatment Processes:* Students will conduct bench-top tests used to monitor drinking water treatment processes. Tests will be performed on water collected from the Truckee River, which supplies approximately 75% of the drinking water in the Reno area. The economic, political, health and environmental issues associated with drinking water quality will be addressed.

f) *Packaging Design:* This experiment simulates a Mars or lunar equipment deployment. Students will work individually to design, construct, and test a container that will protect simulated equipment from breaking when dropped from the top floor of a conveniently located building. The package must be lightweight, have a small volume, and be of a regular shape.

g) *Solar powered boat:* This project is intended to involve a team in various aspects of design and assist them in developing a design methodology. The team is to design, document, and construct a balsa wood boat measuring no more than nine inches, fore to aft, four inches wide and three inches high. The wood, solar cells and a small DC motor will be provided. The drive train and propeller, not to exceed two inches in diameter, will be part of the design effort. Team competition will consist of racing on a straight path for a distance of fifteen feet.

h) *Digital Imaging:* Are there sand dunes on Venus? Is the "face" on Mars for real? Do volcanoes erupt on Jupiter's moon, Io? Recent NASA satellite systems have yielded a wealth of digital imagery of neighboring planets. This imagery is in the public domain, free of charge to teachers and their students. The intent of this project is to expose teachers to digital imagery and their display on computer. A catalog of images, along with public domain display software, will be given to each teacher to carry back to the classroom.

2) Lectures by faculty and practicing engineers:
These weekly lectures will complement and add to the topics addressed in the projects. They will emphasize the importance of ethical, social, economic and political issues in engineering practice. They will include experimental demonstrations or viewing of videotapes where appropriate. For example, discussions of structures subject to potential earthquakes will be complemented by tapes of actual earthquakes, air photographs, geologic and soil maps as well as an earthquake building shaking demo. The ethical, political and economic aspects of projects to build such structures in an urban setting will then be discussed.

In addition to lectures by faculty covering the various areas within their specialties, guest lecturers from local industry and engineering firms will discuss problems and challenges they encounter in the field. Open-ended problems will be posed and the students will be asked to provide solutions. Conflicts between economic, ethical, social and environmental considerations will be addressed.

A few field trips will also be part of the course. The trips will include visits to local engineering firms and construction sites. The lab and lectures will be coordinated to help the students see the connections between theory and practice, promote critical thinking skills and help students become more creative in developing useful schema to become better problem solvers.

In addition, the business aspects of engineering, which are a prerequisite for a successful engineering career, will be introduced. This business aspect would fit within the suggested school to work programs that are becoming a part of many states pre-university education. The six major areas of the course model are as follows:

1) Projects to be completed by teams of students;

2) Problems solving skills;

3) Oral and written communication;

4) Economic or business analysis;

5) Ethics and Professionalism and

6) Social and Environmental Issues.

Last, the pre-service teachers will learn how to modify existing secondary science and mathematics courses with the infusion of engineering curricula. These altered courses can lead to new one semester classes built around engineering and technology principles and applications with the intent to motivate and better prepare secondary students for possible SME&T careers.

III. EVALUATION AND DISSIMINATION OF RESULTS

An outside evaluator will develop two instruments to help evaluate the course. The first instrument will be used to measure student attitudes toward science and technology, what kinds of work engineers do and how valued they are by society. It will be administered as a pretest, posttest in the capstone course. The second instrument will be designed for a longitudinal study. It would be given to secondary students in the classes that some of the pre-service and in-service teachers in the capstone course teach. It will be a pretest, posttest attitude scale and knowledge test to measure both attitudes toward the benefits of science and technology and knowledge of engineering principles. It will address such questions as who should study science and technology, who benefits and how engineers support societal needs.

After the new one semester technology courses have been designed for high school students, the students who take the classes will be tracked in a longitudinal study to see how many chose engineering as a college major. Evidence that can be correlated with changes in the high school curricula in the Northern Nevada schools offering the new classes will be investigated. The evidence will be used to determine (a) any increase in the number of high school graduates opting for an engineering education, and (b) any increase in the retention rate of engineering students.

The results of the project will be made available in the form of a CD for the developed capstone course. In addition, a homepage will be developed for the project to provide access to the material developed in the course. The homepage will be publicized at educational conferences and through the contacts of science coordinator in the local school district and the Rural Alliance of school districts. Designers of the course will also attend pertinent national conferences to give presentations on the new course. After some of the results are in, articles concerning them will be submitted for publication in the science and technology education journals and in the IEEE Transactions on Education. Lab manuals of the activities in the high school and college level courses will also be developed for dissemination to Nevada secondary schools and other universities that have teacher-training programs.

IV. DISCUSSION

Currently, few secondary teachers are adequately trained to motivate and help prepare their students for careers in engineering and technology. In particular, few have any knowledge of what engineers actually do. This capstone course is being implemented to provide training for secondary level (grades 7-12) science and mathematics educators so they can have a greater impact in the education of prospective engineers in the US. It is hoped that such courses will increase enrollments in engineering by providing all high school students with a better understanding of the profession. It may also help reduce the attrition rate of Colleges of Engineering if some of the teaching models used in the capstone course become a part of the regular engineering program. Research by Budny et al [15] and LeBold and Sherman [16] has addressed the engineering student retention problem at the university level. But, to our knowledge, not the problem of (a) preparation of high school students both in attitudes toward engineering and in engineering principles and (b) better instruction in university engineering courses as ways of encouraging more university freshman to study engineering and retaining more of the ones who do. From the experience of the authors, current courses in advanced mathematics and science at the high school level (those designed to give students the pre requisite academic knowledge needed to succeed at the university) are generally not aimed at teaching students about what engineers do or how they benefit society.

Furthermore, the new capstone course should promote science literacy and improve perceptions toward technology in general, specifically toward the critical need for engineers in modern technological societies if our quality of life is to continue to improve and progress toward solving environmental problems is to be sustained.

This model is, to our knowledge, a rare attempt to exploit the vast experience of high school teachers to integrate high school and college education in technology and engineering. Many earlier attempts have concentrated on the pedagogical aspect of teaching teachers rather than aiding them in developing content based courses suitable for their audiences and environments. We believe that this new model to prepare pre service secondary science and mathematics teachers with the above describe engineering knowledge can be implemented in universities throughout the US.

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