A Master's Program that Introduces Teachers to Engineering Practice

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Abstract *— Michigan Technological university has developed a new Master of Science in Applied Science Education for inservice teachers. As part of this program, teachers are required to complete a 12 -credit applied science core focusing on real-life engineering applications of math and science. This 12 -credit core consists of three courses offered as summer intensives — The Engineering Process, Engineering Applications in the Physical Sciences, and Engineering Applications in the Earth Sciences. Through these courses students have been exposed to many different engineering disciplines as Michigan Tech faculty explained the societal, economic, and technological significance of key areas in their fields of expertise. This paper describes our Masters' program and provides assessment data from the engineering core courses.*

Index Terms *— K-12 Teaching, Math and Science Applications, Professional Development, and Technological Literacy*

RATIONALE

In 1996, through a project sponsored in part by NSF and NASA, the International Technology Education Association (ITEA) published its report "Technology for All Americans: A Rationale and Structure for the Study of Technology" [1]. This report set a goal of technological literacy for all citizens. Technological literacy is defined as the ability to "use, manage, and understand technology" [2]. A citizenry that adequately understands technology will make better decisions about technological devices and information systems. In a democracy, where citizens routinely make decisions regarding the environment, medical ethics, land use, and defense, it is important that all be technologically literate to some degree.

In today's society, technological literacy is confined mostly to those people who are directly working in technological fields such as engineering, manufacturing, science, or mathematics. The vast majority of American citizens have little or no comprehension of basic concepts upon which technology is based nor do they fully understand the technological issues that are a part of the daily news [3]. Traditional pre-college education in the US has largely ignored technology as a core subject. Although students take courses in mathematics, science, social science, and English, they rarely, if ever, take courses where they integrate these topics and skills, are exposed to the design process, make ethical choices in the use and development of technology, or learn about how engineers and technologists use mathematical and scientific principles in the solution of society's problems [4,5]. A lack of instruction and understanding of technological issues will seriously hamper the ability of future citizens to keep pace with the ever-expanding role of technology in all facets of their lives [6]. In addition, because technology and engineering are incorporated into all aspects of American life, and because technology results from the integration of mathematics/science to solve problems faced by humanity, technology-oriented applications are ideally suited for use in motivating students to learn mathematics and science [7,8]. Engineering- and technology-oriented applications naturally incorporate authentic learning experiences, which are of demonstrated importance in the educational process [9,10].

In an effort to combat technological illiteracy, the ITEA, along with other organizations, recently published Standards for Technology Education for the K-12 curriculum [2]. The 20 standards for technology education are grouped in the following topical areas: 1) Nature of Technology, 2) Technology and Society, 3) Design, 4) Abilities for a Technological World, and 5) The Designed World. Each of the technology standards has benchmarks for grades K-2, 3-5, 6-8, and 9-12.

Engineering involves the application of math and science in the solution of problems that face our society. Although engineers have been responsible for many of the great technological advances in our society (the space program, microcomputers, the transportation system, etc.), engineers have an "image" problem. Most people, including pre-college teachers, simply do not understand what engineers do. When it comes to positively influencing the life and/or career choices of a young person, teachers are in an unparalleled position to offer encouragement for the pursuit of an engineering degree. However, if teachers do not themselves understand the engineering profession, they are not likely to offer this type of encouragement. In May of 2000, Michigan Tech received a grant from the National Science Foundation titled "Engineering Applications in Pre-College Education." As a part of this grant, we pledged to offer a graduate program that featured engineering applications of math and science for inservice teachers. A major goal in offering this program was to provide

teachers with ideas and activities that they could, in turn, use in their classrooms. Through the 2000-01 academic year, we initiated planning for our graduate program, the Master of Science in Applied Science Education (MS-ASE), with the first cadre of students enrolling in the summer of 2001. The program is limited to candidates who have at least one year of teaching experience in the K-12 setting and it is designed for ease of completion by inservice teachers.

THE MS-ASE PROGRAM

The MS-ASE degree is intended to be a graduate degree for inservice secondary mathematics and science teachers with virtually all of the required components offered either as summer-intensives or as online courses. It promotes professional development within the teachers' disciplines and addresses their students' needs. Through their coursework, the teachers who are candidates for the MS-ASE degree must demonstrate advanced ability to integrate engineering and other real-world applications into mathematics and science curricula in grades 7-12. Emphasis on real-world applications is a priority in both state and national standards for secondary mathematics and science education.

In the state of Michigan, new secondary teachers are awarded provisional certification for five years. During that five year period, teachers are required to complete either an 18 hour approved program of study or a master's degree to move from provisional certification to professional certification. Most new teachers, as they work toward their professional certification, simultaneously seek enrollment in a master's degree program in education. There are financial and career benefits of the master's degree that surpass those of professional certification alone. The MS-ASE degree program is designed to meet the needs of inservice teachers, primarily in their first five years of teaching. The MS-ASE degree program consists of the following:

- Engineering Core (12 credits)
- Education Core (6 credits)
- Education Research Report (2 credits)
- Industry or Engineering Research Internship (3-6 credits)
- Math/Science/Education Electives (6-9 credits)

The engineering core consists of three courses, ENG5100-The Engineering Process, ENG5200-Engineering Applications in the Physical Sciences, and ENG5300-Engineering Applications in the Earth Sciences. Instruction for each of the classes in the engineering core takes place during a two-week intensive summer session. The education core consists of three 2-credit courses offered via the Internet during the academic year. The industry or research internship takes place during one or two summer months. In their internship, teachers work alongside engineers in a local industry or governmental agency. The teachers then write a report and develop a teaching unit based on their internship experiences. Of the elective courses, at least one course must be in the area of applied life sciences, since state and national science education standards are grouped according to life, physical, and earth sciences, and since engineering disciplines available at Michigan Tech do not generaly emphasize applications in the life sciences.

Of the three courses in the engineering core, ENG5100 was offered during the summer each year from 2001 to the present. The remaining two courses were offered during the summers of 2002 and 2003, and are slated to be offered again in the summer of 2005. This paper focuses on these three courses that make up the core of the MS-ASE program.

The Engineering Process Course

The Engineering Process course (ENG5100) focuses primarily on Civil and Mechanical Engineering applications of math and science concepts. There were two projects that students completed during this session to allow them to experience the engineering process firsthand. (Please note that the "students" referred to in the following sections were the grade 7-12 teachers enrolled in the MS-ASE degree program.) The first of these projects involved the use of LEGOs and was conducted as follows. On Tuesday afternoon of the first week of the class, students were divided into teams and were told that they were all "Owners." As Owners, they were to describe (in writing) a project that they would like to have constructed out of LEGOs that would perform a function and involved a golf ball, in addition to the LEGOs. They were not given any LEGOs to assist them in the development of these project descriptions. Owner groups then gave their project descriptions to a different team. The teams of students were then told that they were "Engineers" and that they should develop a set of drawings and specifications for the projects detailed in the Owner project descriptions. Engineer teams worked on these drawings and specifications during the evening and brought their completed construction documents to class on Wednesday morning. Students once again passed their documents to another team, and all teams were told that they were "Contractors." (It should be noted student teams were not permitted to be the Contractor on a job for which they were Owner). The Contractors' job was to use the plans given to them by the engineers, develop a cost estimate based on unit prices for LEGOs, procure the

materials required to construct the project, and then to build the project as the engineers and owners looked on. An Michigan Tech faculty member acted as the LEGO supplier, and Contractor teams were sometimes chagrined to find out that yellow LEGOs were sold in lots of five not three, etc. After construction of all projects, class discussion followed.

The second project that students completed involved the design, construction and testing of a truss bridge made of manila file folders. Students were each given a copy of "Designing and Building File-Folder Bridges[4]," which outlines this type of project. Bridge geometric parameters as well as load conditions were modified from those presented in this text so that students would gain the feel of a true "open-ended" design project. Student teams worked intensively on this project over a week-long period. On Thursday of the second week of the course, student bridges were tested to determine their ability to support the specified load. Students then made PowerPoint presentations regarding their design projects and the results of the load testing on Friday of the second week. Student teams were also required to submit design reports complete with sketches and truss force/stress calculations.

The Engineering Applications in the Physical Sciences Course

ENG5200 is designed to introduce the students to various facets of the engineering field with the exclusion of civil engineering, since that discipline is covered in ENG5100. During the summer of 2001, seven faculty were recruited from the College of Engineering and the School of Technology to develop modules in chemical engineering, mechanical engineering, biomedical engineering, electrical engineering, and materials engineering. The modules focus on particular aspects of these engineering fields, and include hands-on experiments that can be used by the students in their classrooms to demonstrate the principles that engineers in these fields utilize in their profession. Sufficient background information was included in each module to introduce the students to the engineering principles. All of the various experiments were performed in the course so that the students could see how the experiments worked. A guideline that was used in developing these experiments was that the cost of materials needed should not exceed $10.

In initial discussions among Michigan Tech faculty involved in preparing for ENG5200, it was decided that the course should emphasize the fact that engineers from the various disciplines work together in industry, and that the course would require the teachers to present a preliminary design for an object that required the integration of expertise from several engineering fields. In addition, during a review of the program during the spring of 2002, it was brought to the faculty's attention that biology teachers in the first offering of ENG5100 felt as if they could not take any information revelant to their discipline back to the classroom. Based on this feedback, the faculty decided to have students perform a preliminary design analysis of a total artificial heart (TAH). Choosing this problem allowed the teachers not only to see that electrical, mechanical, biomedical and materials engineers needed to work together in order to design the TAH, but it also allowed the faculty to incorporate some of the ethical issues involved with engineering design particularly in the field of biomedical engineering. In order for the students to perform the design analysis, they needed to be introduced to the various aspects of the design process. This was done in the first half-day of the course.

The students were divided into groups of 3 students the first morning of the first week of the class. They were then assigned one facet of the initial design of the TAH. During the first year, these groups looked at 5 design issues: fit of the system, pump performance, biocompatibility, reliability, and quality of life. These focus areas were modified during the second year because a smaller number of students enrolled in the course. During the second year three groups of students looked at design considerations involving the fit of the system and quality of life, pump performance and reliability, and biocompatibility and reliability. During the two week course, the students researched background material about what requirements would be needed in these different areas and presented their analysis in an oral 10-15 minute in-class presentation during the last afternoon of the class. These presentations were reviewed by several of the faculty involved in the course. These faculty made written comments that were then synthesized into an overall review given to each of the design groups.

The Engineering Applications in the Earth Sciences Course

Like ENG5200, ENG5300 was offered for the first time during the summer of 2002, and for the second time during the summer of 2003. ENG5300 focuses on the ways in which engineering practices are applied in problems drawn from earth sciences. Earth science is a broad discipline that includes study of the lithosphere, hydrosphere, atmosphere, and biosphere. In ENG5300 we addressed only a subset of potential earth science topics, all of which were generally related to environmental science and natural hazards. We chose an environmental focus because it allowed us to incorporate field experiences into the course, and to demonstrate the relevance of the course's activities by showing how laboratory methods or mathematical calculations are used to address real-world problems.

Field experiences are typically an important component of earth science instruction because they naturally incorporate hands-on learning, peer-learning, small-group instruction, and problem-solving. All of these pedagogical devices contribute

to improved student learning outcomes [11]. Teachers who participated in the course were encouraged to incorporate field-based activities into their own courses whenever possible.

During the 2002 offering of the course, the field experience was conducted on the first day of the course during a six-hour intensive session at a local stream. Prior to the field experience, teachers were given an overview of the course's content, goals, and requirements. Content-area instruction prior to the field experience also introduced teachers to the field site, and the use of topographic maps, compasses, and GPS in field studies. Web-based hydrological data were available for the stream through the U.S. Geological Survey's website. During the stream-based field session, teachers were broken into four small groups, each of which worked with a Michigan Tech faculty member to collect data or samples that would later be investigated further in the classroom and laboratory. Each group worked with an individual faculty member for approximately 1-1/2 hours, and then migrated to a different faculty member. This allowed the faculty to focus on their own particular areas of expertise, and consistently expose the teachers to best-practices.

During the subsequent six days of the course, teachers were taught how to delineate and determine the area of watersheds, apply basic open-channel flow equations and construct stream hydrographs, perform grain-size analysis, apply and test equations for sediment entrainment and transport, perform and interpret water chemistry tests, and analyze and interpret oxygen demand data. All of the laboratory or classroom activities were tied directly to the data or samples collected by the teachers in the field during the first day of the course. Use of U.S. Geological Survey data available on the web was required, and teachers were encouraged to access data available from other governmental entities and to compare data for different geographic areas (including their home watersheds.

During the last three days of the course, teachers were asked to consider large-scale earth science topics related to natural hazards. Earthquake magnitudes and epicenters were identified using paper seismograms and the Virtual Earthquake website [12]. The effect of earthquakes on structures was investigated using "shake-tables" in the lab. Global climate change, its potential consequences, and its relationship to greenhouse gases were investigated using web-based data sets [13].

EVALUATION OF THE COURSES

The teachers' level of achievement in each of the engineering core courses was determined in part through the use of homework and laboratory assignments that were graded in the traditional fashion. Teachers were encouraged to work in groups, and homework and lab assignments were turned in by groups or individuals. Teachers were also required to keep an individual learning log that was handed in each day. In the learning log, teachers described what they felt they were supposed to have learned during the day, and whether or not they felt that they had successfully mastered the material. They were also asked to review the Michigan State Science and Mathematics Content Standards and Benchmarks and identify which were addressed during the day. Finally they were asked to brainstorm in the learning log about how they could incorporate one or more of the day's activities into their own teaching. The learning log was not graded, and in general the instructors made no comments on the logs. Instead instructors used the log to help guide their preparation for the succeeding day's instruction. The learning logs also helped course instructors to understand what material was viewed as particularly challenging or straightforward by the teachers.

Prior to the last afternoon of each of the courses, the teachers were required to work in a small group to fully develop one of their brainstorming ideas into a outline of a unit plan that could be implemented in their own classroom. They shared their outlines with the rest of the class during the last afternoon of the course. Following the summer intensive portion of the courses, the teachers were asked to use their outlines to guide them in developing a complete unit plan that was to be turned in prior to the end of the calendar year. Final grades in the course were determined based on performance during the summer intensive (75% of final grade) and the quality of the unit plan (25% of final grade).

Results of Pre-/Post- Surveys

Michigan Tech faculty who instructed the courses were asked to provide question pairs for pre- and post-testing based on the material they presented. These question pairs were divided into two separate exams. Half of the students completed Exam A as a pre-test and the other half completed Exam B as their pre-test. At the end of the two-week session, students were given the opposite exam as a post-test. Test items included general questions regarding the engineering profession as well as questions about specific applications they worked on during the course. For example, there were questions where students were given a simple truss and asked to calculate the loads in members and reaction forces, or to identify any zero-force members present. It was found that students scored significantly higher on the post-test (average=19.5/21) than they had on the pre-test (average score=9/23) and the gain was statistically significant ($p<0.001$).

In addition, students were given a pre- and post-course attitudinal survey. Some of the findings from this survey are[8]:

- Students in the MSASE program have demonstrated statistically significant improvements in content knowledge both in the areas of science and education. In-service K-12 teachers are retaining valuable information during their required coursework.
- There have been changes in amount of enthusiasm that graduate students have for teaching overall. The enthusiasm of the instructors was reported to be contagious and inspiring.
- The courses overall have produced shifts in the amount of support that students felt from other members of the educational community. Group activities seemed to encourage this change.
- Students dispelled some of their misconceptions about the accessibility of engineering principles, the content of the discipline, and the purposes and applications of engineering.
- Students appreciated the availability and approachability of faculty and staff

CONCLUSIONS

The MS-ASE degree program has been successfully launched at Michigan Tech. Since its inception in 2001, more than 40 inservice teachers have enrolled in it—some have already graduated. Michigan Tech engineering faculty are learning a lot about the world secondary-level teachers work in, and the teahers are learning a lot about engineering. Each teacher has written several teaching units for his/her classroom designed to introduce pre-college students to engineering problem-solving and design. As faculty and teachers continue to interact, the courses will change to better capitalize on existing technologies and focus content. As more teachers come through this program, the network of secondary teachers with common interests will grow and eventually we may see an increase in the number of students who pursue engineering studies.

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