DESIGNING A GRADUATE EDUCATION COURSE FOR DESIGN, ENGINEERING, AND TECHNOLOGICAL CONCEPTS FOR K-12 TEACHERS

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Abstract - Arizona State University has had several programs for in-service training of teachers, counselors, and administrators to better understand Design, Engineering, and Technology (DET). However, a need was identified to develop pre-service or graduate courses for education majors that addressed DET concepts and linked them to science and technological standards. A team of educators from the College of Engineering and Applied Sciences and the College of Education designed a pilot graduate education course for DET Concepts for K-12 teachers. Sponsored by a National Science Foundation planning grant, the team formulated a needs assessment questionnaire during Fall 2002 with K-12 teachers to evaluate teachers’ perceptions, knowledge, and need of DET. The results of this survey were incorporated in the designing of the graduate course “Bridging Education and Engineering.” This paper will describe the course objectives, the labs, the assessment. Some preliminary observations are also offered.

Index Terms – Engineering Design, Technology Education, Pilot Course.

INTRODUCTION

A clash of cultures or complementary cohorts? It has been a bit of both for a team of faculty from the College of Education and the College of Engineering and Applied Sciences (COE and CEAS) at Arizona State University working on a planning grant from the NSF program, Bridging Education and Engineering (BEE) [1]. The grant, entitled “Design, Engineering, and Technology (DET) Expansion for K-12 Teachers”, is lead by CEAS Dean Peter Crouch and COE Dean Eugene Garcia and is administered and coordinated by the Don Evans, the head of the Center for Research on Education in Science, Mathematics, Engineering, and Technology (CRESMET). The overall goal of the BEE program is to use knowledge acquired from grant activities to plan for larger scale initiatives.

In 1996 the National Research Council created “Science and Technology” content standards as a part of the National Science Education Standards (NSES). Design is considered to be an essential approach to teaching and learning the “Science and Technology” content standards. The initial grant writing effort was stimulated by some important questions relative to these standards. In response to the query, “What do engineers do?” faculty said that engineers designed and manufactured “things” for the betterment of society. COE faculty were asked, “Do K-12 teachers teach any design, engineering, and technology (DET) in their classrooms, and if so, how does their pre-service curriculum prepare them for it? Discussion and debate on these questions led to the development of the proposal with two major thrusts. The first was the creation of a survey entitled, “Teacher Questionnaire on Technological Education for Teachers of Science in K-12 Schools”. The second thrust was the creation of a pilot course on technological design for education majors that was to be taught by a team of CEAS and COE faculty.

The proposal was funded, the survey given, and the course is underway. Some of the important findings of the survey were that teachers felt that: it is important to teach DET to their students, that they had little formal DET training in their pre-service curriculum, and that they would like to learn more DET in workshops and/or courses. Another important finding was that the teachers felt that people tended to stereotype woman and minorities as less capable than males to do well in engineering. The faculty felt that this attitude might cause teachers and counselors to steer well-qualified females and minorities away from engineering in college or as a profession. Engineering is one of the least equitable professions for gender diversity where

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females represent only 11% of the workforce [2]. It was decided that the topic of diversity needed to be emphasized in the design of the pilot course.

A focus group consisting of science and mathematics K-12 teachers was enlisted to critique and refine the survey and the pilot course concept. The focus group indicated that it would be difficult to offer new curriculum or modules within the current Arizona K-12 structure and that the likelihood of success would be higher if teachers were capable of integrating the concepts of DET into the existing curriculum. They further indicated that there were misconceptions regarding DET and that context and social relevance was an important element in teaching and learning DET.

A number of researchers have; a) introduced engineering concepts to pre-college students through summer programs, b) developed in-service teacher training that helped teachers integrate engineering concepts into the curriculum, and c) created engineering modules for the classroom. All of these efforts have employed good pedagogy using inquiry, group or teamwork, and problem solving. However, the primary focus of these efforts has been on activities that emphasize academic content in mathematics, physics, engineering and technology [3]-[5].

The pilot course needed to address more than content. It needed to be presented within a context suitable for the student and include social relevance and gender equity.

A problem-based learning approach was selected as a framework for many of the course activities. Problem-based learning provides strategies by engaging students in relevant real-life experiences, situations, or problems of their own choosing. Problem-based learning is rooted in the theories of learner-centered education of John Dewey [6]-[7]. The problem-based approach is ideally suited for addressing design projects and design laboratory activities, which are required to be open-ended with alternative solutions [8]-[9].

A graduate level pilot course was thus designed to include the identified needs and address the research questions that must be answered before programmatic changes can be completed, including the design and implementation of pre-service and post-service courses and workshops. Students in the pilot course, being graduate students in science education, are learning how to infuse design, engineering, and technology fundamentals into curricula by participating in the engineering design and implementation process to create artifacts or products—i.e., contextualized problems.

As the students gain experience in the engineering design process they participate in transfer activities to map the DET knowledge gained to lesson plans based on the K-12 state and national standards for engineering design and technology. Students are also exploring appropriate models of learning and assessment for DET as well as considering gender and equity issues within DET as they develop curricular materials and address the research questions. Assessing what skills and knowledge students learn and how well they learn them will guide follow-on programmatic changes. The pilot course is currently being taught to nine graduate students from the college of education by faculty from both the college of education and the college of engineering and applied science. It is anticipated that this first implementation of the course will be used to finalize the course design.

The pilot course is taught in the Integrated Manufacturing Engineering Laboratory (IMEL). The IMEL is used for project work in the undergraduate engineering design core courses. The IMEL houses workbenches for project construction, whiteboards for presentations, a computer projector, and computers for presentation development, programming, and analysis. The laboratory resources include a variety of basic hand tools that can be used for construction of automated devices such as cutting tools, soldering tools, clamps, screwdrivers, and drills. The IMEL also has tools for electronic device construction (e.g. power supplies, sensors, and actuators) and tools for electronic device testing (e.g. volt meters and data loggers). Basic construction materials are also available such as plastic, metal, wood, wires, and adhesives.

**ANTICIPATED COURSE OUTCOMES**

We anticipate that the pilot course will refine the course content, the course structure, and the mode of instruction. We also expect that examples of DET integration into the current K-12 curriculum will be developed and that these examples will be linked to the standards.

The education faculty members on the course design team will learn the engineering design process, scalability, applicability, and the range of DET concepts appropriate for teacher education programs—and by example, appropriate for engineering courses. Most education faculty have no training in, and little knowledge of, these concepts.

The engineering faculty members on the course design team will learn about research-based course development, teaching to standards, contextualized activities, and student-centered pedagogy. Most engineering faculty have no training in, and little knowledge of, these concepts. They also have had little training in teaching methods that support gender and diversity differences.

Several learning objectives, described in the next section, have been developed for the students in the course.

**COURSE DESCRIPTION**

The learning outcomes for the pilot course are:

- Students will have knowledge of Design, Engineering, and Technology (DET) appropriate for developing K-12 content.
- Students will have knowledge of the engineering design process.
- Students will have knowledge of the K-12 standards for engineering design and technology.
Students will be able to transfer the engineering design process and DET to K-12 instructional content.

Students will have knowledge of gender and equity issues related to DET and transfer.

Students will have knowledge of models of learning and assessment for DET.

**The Course Structure**

The pilot course is taught once a week for 2 hours and 50 minutes over a 15-week period. The course was designed to be highly interactive, consisting of a repetitive sequence of activities as follows:

1. a pretest of learning concepts,
2. reflections and discussion on readings,
3. short concept presentations,
4. team-based inquiry activities,
5. activity reports,
6. transfer activities,
7. transfer reports, and
8. a posttest of learning concepts.

Each class begins with a pretest consisting of 2-4 questions, which assess the participants’ knowledge of the concepts covered on that day. The same test is given at the end of the day as a posttest. For example, in one class students were asked to define “sensor”, to give an example of a device with a sensor, and to describe how they would characterize a sensor. The pretest questions help the instructors to develop an inventory of student concepts of DET prior to classroom learning. The questions also help guide the students learning for the class and are used to evaluate the participants learning of the concepts.

Each week students read 2-4 articles and write a short reflection on their readings. The readings cover many topics including: Education standards, the engineering design process, models of learning, gender equity, nature of technology, and case studies relative to DET and K-12 instruction. After the pretest all course participants take a few minutes to offer their reflections, ask questions, and discuss concepts.

The concept presentations typically follow the reflections and discussion and consist of the background information necessary to complete the class activities for the day. For example, a concept presentation on the operating principle of a power supply and a voltmeter is given to prepare students for inquiry based hands-on discovery of the functioning characteristics of a variety of electronic sensors. Concept presentations include mini-lectures and demonstrations and are designed to be relatively short, typically 10-15 minutes.

Six laboratory activities were designed for the pilot course (see Table 1). The laboratory activities were designed to build a foundation in DET and the engineering design process. The laboratory activities are hands-on experiences also intended to increase the students’ self-confidence and efficacy. The DET and engineering design process foundation is the basis for creating K-12 integrated lesson plans through transfer activities and this enables the development and implementation of a course design project.

**TABLE I COURSE/LABORATORY ACTIVITIES**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
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<tbody>
<tr>
<td>Characterizing Sensors</td>
<td>Teams characterize 2-3 sensors using voltmeters and power supplies and describe the operating principle of the sensor (each team is given a unique set of sensors).</td>
</tr>
<tr>
<td>Characterizing Actuators</td>
<td>Teams characterize 2-3 actuators using voltmeters and measuring devices and describe the operating principle of the actuator (each team is given a unique set of actuators).</td>
</tr>
<tr>
<td>Connecting Micro Processors</td>
<td>Teams characterize the relationship between sensors and actuators connected to a microprocessor and then change the relationship (each team is given a unique sensor/actor system).</td>
</tr>
<tr>
<td>Problem Identification</td>
<td>Teams use problem identification techniques to determine why a miniature wheeled robot does not travel on a straight path and then correct the problem (each team is given a robot with a different problem).</td>
</tr>
<tr>
<td>Solution Generation</td>
<td>Teams generate alternative problem and design solutions for a given problem statement.</td>
</tr>
<tr>
<td>Modeling and Analysis</td>
<td>Teams create and refine mathematical models to predict the time it will take for a device to climb an incline and then compare models to actual climb time (each team is given interchangeable device components).</td>
</tr>
</tbody>
</table>

Students participate in the laboratories in teams of 3-4 students. The laboratory activities are inquiry-based, where students learn through discovery. Each laboratory begins with a task statement and perhaps a few constraints. For example, after a concept presentation on power supplies and voltmeters, student teams were given two different electronic sensors, a power supply and a voltmeter. Students were then asked to characterize the sensors and explain the operating principle. A typical sensor for this lab was one that detects the distance from the sensor to an object and outputs a voltage related to the distance. The instructors move between the teams and offer guidance only when the students struggle for an extended period. An engineering student who has taken the introductory design course is also present for technical assistance and repair. Teams are given additional resources if requested and available and can use the Internet. The first output of the laboratory is a team report that is prepared on whiteboard and presented to the class. Teams are encouraged to use graphical diagrams, numerical data, and textual detail in the reports.

Many of the reports are followed by classroom transfer activities where teams create lesson plans and demonstration examples of integrating the concepts into their curriculum to reflect DET, gender equity, and standards. Teams are asked to transfer the concepts from the laboratories to a lesson plan for a specified grade-level. A report of the lesson plan is then presented to the class. These reports are also created on whiteboards. An example of a transfer lesson plan for
grades 7-12 was to have the students suggest how sensors and actuators (output devices) could be used to help the hearing or seeing impaired to recognize events that they might have difficulties recognizing (e.g. a doorbell for the hearing impaired).

About the middle of the semester the teams are given an open-ended semester design project. In the design project teams design and build a device of their choice that uses sensors, actuators, and a microprocessor. They are also asked to use a design notebook to document their implementation of the engineering design process. The design project also includes three presentations. In the first presentation the teams specify the design objectives (problem addressed, functional requirements and any constraints and limitations to their design). They also sketch some conceptual designs and create a team schedule and assign team roles. In the second presentation teams present a drawing or model of their final detailed design concept. Teams also explain how and why they choose their final design and discuss any modeling and analysis used. The final presentation is demonstration of the final artifact with an assessment of how well the artifact meets the team design objectives. We call this final presentation the “Design Fair”.

Course Evaluation and Assessment

Students are evaluated on the basis of five activities. These are weekly reflection papers based on the assigned readings, class discussions of the readings, lesson plans created at the end of each class meeting, a one page project description/proposal, the project itself, and the project presentation. Rubrics or guidelines related to course outcomes are used to evaluate the activities.

The weekly reflection papers are submitted electronically and used to monitor understanding and make adjustments to the course. The reflection paper addresses implications for curriculum based on the data presented in the readings, teaching, and personal experiences. This is an individual activity. In addition each person is expected to participate in the discussion of the readings and to compare their reflections with those of the other class members.

The lesson plans are a transfer activity that requires students to apply the concepts explored in the lab activities of the class into a lesson in ways that take into consideration issues of gender and social relevance. The lessons must also include the national science standards.

The class culminates in a project based on a one-page student proposal. After receiving feedback on the proposal the students engage in building and testing their project. At the end of the semester, the project is presented at a “Design Fair”.

Students were also given an opportunity to evaluate the class through focus groups. At the time of this article, two focus groups had been held. The first focus group was conducted at the start of the fourth class period and the second was held at the start of the eighth class period. The information gathered through the focus groups allowed for process evaluation of the experimental course. Seven students were involved in the first focus group. They indicated that they liked “playing as a way of learning.” The hands-on labs were challenging learning experiences that allowed the group members to learn not only from the activities, but also from each other. Second, the class found that they had fallen into gender typical behavior that they often see in their own classrooms. Men were taking the dominant roles and would “play longer and get off task.” Women became the group recorders and when they made suggestions the men often would not listen. As a group, both the men and the women wanted to change their behaviors. They noted that any teacher/faculty has to “notice gender differences and mix up groups” as an intervention.

When the students met for the second focus group, nine students participated in the discussion. They reported that the faculty were very receptive to their feedback. Not only did the faculty acknowledge that the group dynamics might not be as effective as desired, but the faculty told the students to solve this problem in a way that would work best for the students. Three females chose to form an all-female group and the other students decided to form mixed-sex groups. Not only did the students learn more about gender role behaviors and how they were enacting male or female stereotypical behaviors, they also began to understand how similar behaviors could be occurring in their classrooms as well. By taking control and ownership for their own behaviors, students reported that this resulted in everyone “buying into the projects.” They also began to see how the assigned readings applied not only to their classrooms but also to their own behaviors and attitudes.

Time was a consistent concern raised by students. Everyone wanted more time to “play in the lab.” They also wanted more time “to synthesize what we are learning.” Some indicated that they would be willing to stay an extra hour or even take the course for four credits instead of three credits. Comments made by several students reflect the attitudes of all students about the class—“Don’t shorten lab!”; We are learning to “bridge the gap between engineering and education” and learning what “engineering is all about”; and “this class is great.”

Course Implementation and Observations

In this section we report on some implementation issues and offer some observations. Most students that enrolled for the course did not have experience with the type of tools used in IMEL. Some of the students expressed feelings of apprehension about using the tools and devices. Many of the students have experienced that now after eight weeks, this is now the one course that they would not miss. Students stopped demonstrating or indicating apprehension by the second laboratory session. Many of the students have colleagues that did not take the course due to apprehension and have reported that they wish they had.
Each laboratory activity is carefully designed to reduce technical difficulties and enhance the learning experience. Many devices are pre-wired and developed to be as modular as possible. The design of the course content and the laboratories has taken much more time than the instruction of the course. Despite careful planning and set-up, there have been some technical problems that would have been difficult to overcome without the aid of a technician or the engineering student assistant. For example, in the laboratory that explores connecting sensors and actuators with the microprocessors, the wiring of one of the sensors to a microprocessor was inadvertently detached. In another case a student team accidentally terminated a computer program that contained the code for their project. These problems were rapidly remedied, but could be compounded with a larger number of students. The follow-up development will require refinement in the complexity of the laboratories. Figure 1 shows the laboratory set-up for one of the actuator laboratory activities. In this figure a motor is connected to a power supply. The motor speed is increased as the voltage from the power supply is increased. Here the students are trying to devise a technique for measuring the speed of the motor.

Many of the students have reported that the course has already impacted their work. Reports include being asked to lead the integration of technology (not computer technology) in her school. Another student reports that they have incorporated course concepts into a national training and education program. Many of the students have indicated that their initial understanding of DET has been significantly changed. A particular example is the use of the word “technology”. Most education students understand this term to be related to computer technology. The engineering use of technology refers to the broader set of devices and processes created by humans.

We have attempted to create a context for all laboratory activities. The students have reflected upon the creation of context in their reports and transfer activities. Figure 2 shows some conceptual design development. In the top of the figure an analogy is made to the human body. Sensors are related to the eyes, the microprocessor to the brain, and an actuator is related to the foot. The conceptual design presents a system where a sensor is used to keep track of the number of people in line for a ride at an amusement park. The processor calculates the time people will have to wait in line and an actuator changes the duration of the ride based on the length of the line. Figure 3 shows an example of a transfer activity report designed for 7th grade students. This transfer activity was developed after the “connecting microprocessors” laboratory.

Different team structures have been used in the laboratories. In the first two laboratory activities the students formed their own teams. After these first two laboratories some of the students noted that the male team members tended to lead the laboratory activities and suggested a different team structure. For subsequent laboratory activities, the students formed their own teams, two of which included both males and females and one that was entirely female. There were several noted differences in the approach of the different teams. One of the differences was that the all female team spent a significantly greater amount of time discussing and planning before interacting with the physical devices. The all male team members immediately interacted with the devices and spent less time planning and discussing.

The final projects included an ultrasonic wand designed for hearing impaired youth, a training golf club that provides feedback on the location of a golf ball upon contact with the club, and an electronic license plate. Figure 4 shows the golf club team with their final design poster.

Students were required to identify all design components and to manufacture all components that could not be purchased. Students overwhelmingly expressed surprise at the complexity of transforming design concepts.
to functioning prototypes, leading to an enhanced understanding of the engineering design process. All of the initial conceptual designs were modified during the project implementation due to implementation difficulties.

CONCLUSIONS AND EVALUATION

Both the course instructors and the students are excited about the course thus far. The engineering professors and education professor have enjoyed and appreciated the synergy of work with a profession with a different background. The engineering professors, especially, have learned to give up the “lecture” unless short.

Additional evaluation will be done at the conclusion of the course and suggestions made for improving the course. Educational students that have heard about the course are asking that the course be offered again.

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REFERENCES