Engineering for Educators

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Abstract

To increase the preparedness for and interest in Engineering, as well as general math-science skills in our youth, a new course has been developed in cooperation with the Education College at Boise State University called "Engineering for Educators". The goal is to reach more K-12 students for longer periods of time and at earlier ages than most outreach activities allow. The education students are mixed with the engineering students in the existing "Introduction to Engineering" course. The education students get an extra hour a week with an education professor to discuss how the engineering projects could be used in the K-12 classroom to meet state teaching standards for math and science as well as reading, writing and other non-technical subjects.

Combining the educators in with the engineers has three main benefits. First, the educators get to see what the engineering students actually learn without the material being watered down. Second, the teaching load is distributed by including more bodies in existing sections requiring the education professor to only prepare the discussion lecture and not the engineering projects. Third, by interacting with the engineering students, the educators can break down some of their stereotypical views of engineers and they may be more likely to recommend this field to their future K-12 students when they see a student with the appropriate interests.

Although this reports on the first semester that the course was offered, those involved have seen several improvements in student attitude, both engineering and education students. However, the most telling improvement is the confidence level of the education students. They have found that they can play a valuable part in any team project. Although they may not feel they have the necessary math skills they are able to organize, analyze and synthesize the ideas. Also, once the math is explained to them they realize that they do understand the concepts. The education students are also seeing numerous ways that the course projects could be used in the schools.

Plans are to continue to offer this course in the following semesters with expectations for higher enrollment including some practicing teachers. Discussion is beginning on making this course an acceptable substitute for the math & science methods course offered by the Education College.

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Introduction

The desire to increase the preparedness for and interest in engineering, as well as general math-science skills in our youth has been prevalent for many years. Many methods have been used towards this goal. In the past 10 years a greater focus has been placed on the National Science Standards and the National Mathematics Standards. The basic goals of these standards have been adopted by most states over the course of these 10 years. Among those goals is a new approach to teaching both mathematics and science. Traditional methods of instruction focused on the memorization of facts with little connection to the real world. The standards set goals to focus more on the process skills necessary to learn the subjects. This originally meant a "hand's-on" approach to teaching. However, it is not enough to do hand's-on activities. There has to be a process of meaning making that is developed from those concrete experiences. It is from this that students are now asked to not only do hand's-on but also mind's-on activities. This goal is often met by engineering projects.

The most common approach taken to reach younger students and expose them to engineering is for engineering faculty to go into the public schools or to invite the students to the university for contests or intensive camps. While these activities are usually very beneficial to the receiving students, this has the drawback that it only reaches a small percentage of the K-12 students, and is very time consuming for the engineering faculty. These activities also usually have a relatively short duration compared to the other educational activities, and are often viewed by the receiving students as a break from the "reality" of school rather than an integral part of it. The other weakness is that all too often these outreach activities reach the students in high school when the students have generally decided that they have an interest in math/science/engineering, or as all too commonly occurs, that they do not have such an interest.

The goal of those involved in this melding of Engineering and Education is to reach more K-12 students for longer periods of time and at earlier ages than most outreach activities allow. Massachusetts decided that part of the solution was to require that engineering be taught in the K-12 classroom along side reading, math and science. "The Massachusetts Science and Technology/Engineering Curriculum Framework is one of seven curriculum frameworks that advance Massachusetts's educational reform in learning, teaching, and assessment... Its purpose is to guide teachers and curriculum coordinators about what content should be taught from PreK through high school" [1]. In Idaho similar legislation has not been proposed, but a desire to increase engineering education in the K-12 level exists. An issue that always arises when legislating that some additional material be taught in the classroom is that the teachers need to be prepared to properly and confidently deliver this material. A new course has been developed called "Engineering for Educators" that will enroll education majors in the existing "Introduction to Engineering" course supplemented by a seminar lead by an education faculty member to discuss how the engineering projects could be used in the K-12 classroom to meet state teaching standards for math and science as well as reading, writing and other non-technical subjects.

Combining the educators in with the engineers has three main benefits. First, the educators get to see what the engineering students actually learn without the material being watered down. Second, the teaching load is distributed by including more bodies in existing sections requiring the education professor to only prepare the discussion lecture and not the engineering projects. Third, by interacting with the engineering students, the educators can break down some of their stereotypical views of engineers and they may be more likely to recommend this field to their future K-12 students when they see a student with the appropriate interests.

The remainder of this paper describes how this program developed and logistics involved in actually running the course. Examples of some of the units used in this course and how they apply to the K-12 classroom will be introduced. The paper will conclude with observations gleaned from the preliminary run of this course and an outline of plans for continuing this into the future.

History and Logistics

Collaboration between the Colleges of Engineering and Education at Boise State was started in 2001 after the respective college Deans attended an IEEE sponsored workshop. An ad-hoc committee was formed which introduced the faculty of the respective colleges to each other providing a chance to develop a sense of trust. This led to a collaboration that produced the "Engineering for Educators" course.

Several options were considered for how more engineering could get infused into the curricula in Idaho schools. These options included summer workshops and development of lesson plans packets for in-service teachers. After discussing how we would reach these teachers and convince them to devote time to our agenda it was realized that 100 pre-service education majors graduated from Boise State University each year and that reaching them might be easier since several of their faculty were on this committee and were in a position to change their curricula.

Next the engineering faculty had to be convinced that the presence of education majors in the engineering classroom would not adversely affect the engineering students' education. Engineering majors are expected to be concurrently enrolled in Calculus I when taking "Introduction to Engineering" whereas most education majors do not take calculus. It was decided that education students would be required to have the "Geometry and Probability" mathematics course as a prerequisite for entering the Engineering for Educators course. This would assure the education majors were in their third or fourth year of the program so their maturity could compensate partially for a less rigorous math background. Although Geometry and Probability may not cover the same concepts as the Calculus course, it does focus on some of the same content that students in a Calculus course might have but at a more basic level. For the Engineering for Educator's course to count towards the education curriculum, it needed to be an upper division course and we wanted to make sure that the engineering students wouldn't take this course and try to count it as an upper division engineering elective. The math prerequisite, in addition to assuring the education majors were in the proper point in their program, helped to solve this problem. The education students get an extra hour a week with an education professor to discuss how the engineering projects could be used in the K-12 classroom to meet state teaching standards for math and science as well as reading, writing and other non-technical subjects. This also helped justify the upper division status of the course.

We anticipated that neither the engineering professors nor the education professors would be adequately versed in both the engineering and the pedagogy to develop and teach the whole course alone. Also as the course was developed it would initially have an enrollment too low to justify two full faculty members' time. Putting the education students into the existing "Introduction to Engineering" class became the logical solution. The education professor assisted in the engineering portion of the class collecting ideas on how the material applies to K-12 education and then led the discussion in the weekly education seminar. This resulted in only a slight increase in labor for engineering professors during the start-up phase. There may be an increase in load as new sections are needed. However, this collaboration will allow the engineering college to do more 'service' courses for the university.

The dynamics in the classroom were found to be considerably changed with the presence of the education majors. This was partially due to the percentage of female students increasing from 5% to 10%. This was a benefit to the engineering students. The engineering students were sometimes placed in the position of being the teacher which helped them to better formulate their own ideas as well as learn the content.

Many of the lessons taught in the Introduction to Engineering courses are in close alignment with the standard's based kits developed by the National Science Resource Center (Science and Technology for Children – STC) and those developed by Lawrence Hall of Science at the University of California, Berkeley (Full Option Science System – FOSS). The methodology used in the teaching of science focuses on a hands-on/minds-on approach. Teachers must have the content background to help their students develop meaning from their experiences. In order to do this at the elementary level teachers must get past their own fears about their lack of ability and/or knowledge in the areas of math and science. Through the Engineering for Educators class it was expected that the preservice teachers in elementary education would realize that they have the knowledge and the ability to understand the processes that are taught in the engineering course. It was determined that the Introduction to Engineering course would work well and would only need minor modifications. One reason that it was ideal was that it would introduce educators to the various engineering fields. Many of the activities used by engineering faculty to teach college freshmen about engineering could be easily modified to teach K-12 students about engineering as the activities were mostly hands-on/minds-on activities. If the teachers were prepared to introduce engineering material in their K-12 classroom, the students would see that engineering was an integral part of their education and not just a 'field trip'. It could also show how the theoretical science and mathematics is applied to making many of the things common in the students' lives. If the future teachers were to become acquainted with the engineering field and how it involves everyday concepts and how it could be integrated into their classroom, then they could use it in their classroom on a regular basis for many years to come. This has the advantage of reaching more K-12 students for longer periods of time and at earlier ages than most engineering faculty could based on outreach activities alone.

Activities in the Classroom

The principle goals of an introductory engineering course are to (1) introduce the students to the many fields of engineering available to study, (2) learn how to work in teams, (3) learn how math and science are applied to engineering (4) develop oral and written communication skills as applied in the engineering profession and (5) start actively developing their engineering skills. Many of these goals are equivalent to goals in the K-12 classroom. The biggest differences are in the age and educational preparedness of the student, but since the Introduction to Engineering course is taught to first semester students (just entering Calculus I) and doesn't use very in depth concepts in the math and science courses, this gap has not proved to be that wide.

Projects that are routinely done in Boise State's Introduction to Engineering course include topics in manufacturing, materials, robotics, and electronics. In the manufacturing unit the students develop a process to manufacture peanut butter cracker sandwiches and assess the profitability of their design [2]. The materials unit focuses on building and strength testing composites built from natural materials and glue and comparing the students' designs with wood and particle board. The robotics unit also bridges into biomedical engineering by exploring existing designs of commercially available mechanical arm prostheses. For electronics the students build some small kits where they are asked to verify, among other things, Ohms laws, and learn about resistor codes and bread boards.

Several smaller units are also used in the class to cover small topics or as a start-up or bridge into a larger unit. One such unit was consumer products testing where the students had to choose a product and the metrics on which to evaluate it. Students also dissected a disposable camera, cataloged the parts, and gave a presentation on how it worked and with suggestions on how the design could be improved in regards to some aspect such as manufacturability or environmental responsibility. The final small unit, which will be elaborated on later in this paper is a unit called "Twisters." Here students explored design variables and operator issues, and used Excel to graph some of the quantitative results.

Consumer Product Testing

Students were told to find a common household product and do a comparative evaluation of some aspect of its quality among different brands. The students were responsible for deciding on the metric they would use. The products chosen by the students in the course cover a wide range of products such as batteries, glue, hair dryers, automotive head lights and staple guns. The Education students chose to evaluate pencil erasers. They investigated how many strokes it took of several brands to completely erase a line from paper, how well each subjectively erased the line.

This activity could be used in the elementary school by having students select a product from their environment and test it. The tests would be much more basic but still useful. Students would not only collect data, which is a standard in both science and mathematics at the elementary level, but they could also write up their findings. This is not only a language skill but also a skill in the area of science. The National Science Standards emphasize the need to write up reports on science experiments.

This is the first unit that the students complete in the Introduction to Engineering class. Although it does not focus on a particular field of engineering it does help the students begin the process of team building. It also helps them focus on the proper method of collecting and presenting data.

Peanut Butter Cracker Manufacturing Unit

Teams of students develop a method to assemble peanut butter and Ritz style crackers into baggies of 10 cracker sandwiches. The student teams design the assembly process, build (or buy) any equipment needed for this procedure, develop a training routine for the soon to be 'hired' unskilled operators (usually volunteers from the faculty and staff in the College of Engineering). They also need to decide how fast they can make these crackers, and the economics of hiring 1, 2 or more 'unskilled' workers to do the operation of the assembly equipment during their trial run. The students then get 10 minutes to 'train' the unskilled operators in how to use the equipment and the process they are expected to complete. Then the unskilled operators are given ten minutes to assemble the crackers. The teams measure the cracker sandwiches are made within the specified thickness constraints and weight constraints divided by the cost of their operators. They also need to calculate the cost of the skilled or unskilled workers involved in the 10 minute trial (the students doing the design are considered 'skilled' operators and may assist if they feel it is economical to hire themselves at a higher 'pay rate'). The teams earn points based on the average cost per package of 10 cracker sandwiches made during the trials. They analyze costs and how to make the process profitable. Teams were also expected to predict their profit and then had to compare their results with their actual profit and then comment on how they should modify their process for the future.

This same unit relates to the K-12 education by introducing students to weights and measures. It also introduces the subject of economics. In this project students must do a significant amount of simple calculations showing where the calculations could be used in a 'real world' environment. The teams were required to describe the steps that the untrained operators would need to complete to successfully manufacture the cracker sandwiches. Here the necessity of writing assignments with very clear and detailed steps is something that is needed when giving assignments to elementary students. Those involved in this class found that this was a very significant lesson to be learned.

Twisters

The 'Twisters' unit was a bridge unit that helped build the teams for the next phase of the course. It had the students teams take a piece of 8 ½ x 11" paper and cut it to make a 'twister helicopter,' see Figure 1. The goal was to be able to drop the twister so that it would land as close to a target as possible. Students were given the ability to choose the length of the stem, the body and the 'wings' and the number of paperclips to attach at the bottom of the stem to make the best design. Three trials were conducted. First, from the second floor balcony one team member was blindfolded and the others had to use verbal instructions to tell the 'dropper' where to place his or her hand so the twister would be in the best position when dropped. The second trial was also from the second floor balcony, but this time the instructions were to be without verbal communication and only with touch. The third experiment was from the third floor balcony and

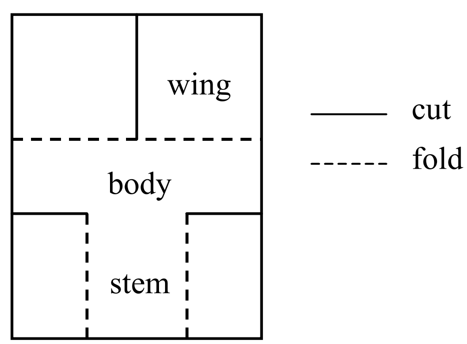

Figure 1: Diagram for 'twister helicopter'.

the dropper could look and make the decision him/herself or through the help of the team mates. The team judged their success by how close to the designated target the twister landed.

A second phase of tests were then done to choose one variable of the design such as weight or wing length and vary this quantity in steps, while holding all other variables constant. The team would drop the twister 10 times and then chart the time to fall versus the changing parameter. This charting was done in Excel as an introduction to that tool and its capabilities.

This when brought to the Engineering for Educators seminar was likened to another activity in one of the FOSS kits that is used to teach elementary students about the concept of variables. In using the FOSS kit Variables, students are asked to design various devices and then gather data on their ability to do what is needed. Like the Twisters, the elementary students must control for the variables that might affect their device.

Composite Materials

The students used an assortment of fibers to build a composite material. They had their choice of straw, corn husks and recycled shredded paper. They used white glue to bind the fibers together. All these materials were put into a form to guarantee similar resulting sizes and to keep the materials together. Students got to chose what combination of these three fibers they would use and how to lay it in the mold. Some students just placed them in the mold in neat rows and some spent considerable time braiding the fibers before placing them in the mold. After they built their composites, they evaluate the composites with a tensile tester with a three point loading scheme to measure the stress-strain behavior and flexural strength. They compared their composite to a block of wood, particle board and wafer board. They evaluated the strength to weight ratio, they estimated the cost of producing their composite material with respect to wood, the ease of fabrication and ease of use as well as the environmental impact of their composite.

In the elementary classroom students could replicate this experiment because it uses materials readily available (except the strain gauge). This composite material is a small scale man made version of large scale earth and soil formations. A part of the earth science standard [3] students are introduced to how the products of the earth form from layers of materials like pebbles, sand and silt which determine whether they are strong or weak. Some natural formations are weak and collapse, while some remain along time until they are eroded away. The difference is the kinds of materials used, how they bind together, the size of the structure, and that these composite materials are man made. Showing students that many engineering concepts are inspired by nature could lead to discussion of other common things designed by engineers that students use regularly that were inspired by nature.

Circuits

The "Circuits" unit had the students build several circuits and become familiar with the functions of common elements such as resistors, diodes, transistors, and capacitors. The students had to work with schematics, circuit boards, soldering irons and multi-meters to build their project. They began the unit with simple circuits on a solderless circuit board and progressed to building more complex circuitry on a printed circuit board. This was followed by assembling a project kit to build a device that involved motors, sensors and/or LEDs. The students did an analysis of the design and described it to the class. The requirements for this description took into account the fact that none of these students had taken a circuits course previously.

In the elementary school students are first introduced to the basic properties of electricity as they learn about electric circuits and the parts of a light bulb. Students then begin to learn about conductors and insulators and about the symbols used to represent the parts of a circuit in circuit diagrams exploring different kinds of circuits and switches. Finally students will construct various items and investigate the properties of diodes. This ties in closely with the national standards of light, heat, electricity, and magnetism as well as science as inquiry and science as technology. The study of electric circuits is closely associated with problem solving which is a major standard in mathematics [4].

Having the elementary education students work with the engineering students in the study of circuits helped alleviate the fear that many education students have of anything electrical. They were able to see that it follows a pattern and is easily understood. This should help them as they begin to teach the concepts in the elementary school.

Observations

The initial run of this course was tremendously successful. All of the intended outcomes manifested themselves and some unexpected other perks also appeared. To this date no major shortcomings have been identified. Some of the benefits observed will now be summarized.

It was felt that it was very important that the education majors meet with the Introduction to Engineering class and **not** be separated into a separate engineering class just for education majors. We did not want the engineering components to be watered down for the education majors. As the semester progressed, we saw a significant increase the confidence the education majors had in their individual math and science skills. They realized that if they could do the same math and science based projects that engineering students do, they must have some ability. If the students had been separated, there would be a lingering feeling that it reflected on their ability.

The education majors enrolling in this course are juniors and seniors based on the prerequisites we have set for this course. We have found that this gives them a greater maturity level than the freshman engineering students. This maturity advantage has allowed them to lead better and more than makes up for their weaker math skills and the lack of confidence that comes with that.

We have also found that while we don't announce to the engineering students that these certain students are education majors, through conversation they do become aware of that fact and we have observed a 'big brother' type of protective care being exerted by the engineering students to make sure that they take care of the education majors and don't let them get left behind if a mathematical concept comes that is beyond their skill base.

The dynamics in the classroom were found to be considerably changed with the presence of the education majors. This was partially due to the percentage of female students increasing from 5 to 10%. This is a benefit to the engineering students as well.

The education majors were observed to have different ways of looking at the projects and concepts presented to the students. For example, the engineering students for the product testing unit evaluated things like batteries and nail guns while the education majors chose erasers, a common material in the classroom.

With the education majors working along side the engineering students, it is hypothesized that several stereotypes of what engineers are like have likely been reduced by the education majors actually having met some. The reverse could also be said in that the engineering students have changed their opinion about elementary education majors. Several of the students were surprised to find that the elementary education student's contributions to the group were valuable and in many instances what the group needed in order to build their project correctly.

Future plans

This experimental course could not have been more successful in our opinion for the first run-through. Still there are things we hope to modify. There are plans for extending not just the course but the analysis of the effectiveness of this course.

With one run-through complete, the other education professors can see the success of this course. We are considering plans to make this a permanent course offering (probably once a year) and to allow this as an approved alternative to the Science Curriculum and Instruction course currently required for elementary education majors. We are looking into having education students from a sophomore education class be the operators for the Peanut Butter project. This will expose more elementary education students to this course and possibly influence their course election choices.

We would like to see some secondary math/science education majors also participate in this course. At Boise State, the secondary education programs are administered by the field specific department with limited involvement from the College of Education. With successful completion of this course with elementary education majors, we now have some concrete examples of the course to use in advertising it to these departments.

The benefits of this course to date have only been measured by anecdotal evidence. Starting in Spring 2005 we will start to collect some quantitative data about its effect on the students. We look to collect evidence of how it changes their perception of math and science, since generally elementary education majors have a tendency towards math and science phobia which they unwittingly pass on to their young and impressionable students. Also we plan to follow the students who have completed this course as they go into the field for their practicum and as they become full time practicing teachers. We are interested in how they integrate specific activities from the course into their teaching, what new ideas they develop or seek out on their own and whether they integrate the science and engineering more often into their daily classroom activities than teachers who have not had such a course.

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