AC 2009-1567: ENHANCING INTERACTIONS BETWEEN ENGINEERING PROGRAMS AND THE K-12 SYSTEM

Richard Zollars, Washington State University

Dr. Zollars is a professor in, and Associate Director of, the Gene and Linda Voiland School of Chemical Engineering and Bioengineering at Washington State University. He received his Ph.D. from the University of Colorado. He has been teaching engineering for 30 years. His interests are colloidal/interfacial phenomena, reactor design and engineering education.

Donald Orlich, Washington State University

Don Orlich graduated from the University of Montana in 1953 with a B.A. in Education. He received a Masters of Science Education in 1959 from the University of Utah and an Ed.D. in 1963 from the University of Montana. He taught five years as an elementary and junior high science teacher in Butte, MT before taking a faculty position at Idaho State University. From 1967 to 1994 he was a faculty member in the Department of Education at Washington State University. He currently works at the Science, Mathematics, Engineering Education Center at Washington State University.

Enhancing Interactions Between Engineering Programs and the K-12 System

Background

A problem facing the United States is the declining numbers of students expressing an interest, or majoring, in engineering. Recently the American College Testing organization reported that between 1992 and 2003 the percentage of high school students expressing an interest in majoring in engineering dropped from 9% to 6%[1]. In addition to the lack of numbers there is also the recurring problem of the lack of preparedness among US students in math and science[2]. Indeed, the state of preparedness of US students in science and mathematics at all levels has been under scrutiny following the release of the report "A Nation at Risk" in 1983[3]. This concern has remained constant and was mentioned again in the National Academies Press publication "Educating the Engineer of 2020: Adapting Engineering Education to the New Century."[4] Recommendation 12 in this publication states "*Engineering schools should lend their energies to a national effort to improve math, science, and engineering education at the K-12 level.*" Proper student preparation is further complicated by the fact that the Committee for Economic Development reports that as many as 35% of the mathematics teachers and 45% of the biology teachers do not have majors or minors in these fields[5]. The lack of proper preparation may also be the result of a lack of opportunity for the teachers to periodically refresh their skills.

Many programs have been initiated throughout the country to address these issues. These can be crudely separated into two categories; those focusing on teacher preparedness and those focusing on student supply. There are many programs seeking to address the problem of teacher preparedness in science and mathematics. These range in size from small local efforts up to statewide programs such as the National Science Foundation Statewide Systemic Initiatives. While too numerous to mention here, a representative sampling of these programs can be found in such publications as the "NSF-Supported Undergraduate Faculty Enhancement Projects"[6]. Recent programs that target teacher preparedness include the "Train the Trainer" program[7] and the "Pre-Engineering Instructional and Outreach" program.[8]

Programs seeking to address the problems of enrollments in engineering are even more numerous. The usual program in this category consists of a classroom/laboratory experience where high school students are exposed to engineering with the expectation that these students will then be more likely to enroll in engineering. Typical examples are the "Inspires Curriculum",[9] "Engineering Concepts Curriculum Project",[10] the "Academy Introduction Mission",[11] and the "Texas Pre-Freshman Engineering Program"[12].

A program to address these issues was started in this department in 1993 with funding from the National Science Foundation. The concept for this activity arose from a conversation amongst chemical engineering faculty members on what influenced them to major in engineering. Almost uniformly the conclusion was that it was an influential teacher at the 5th through 9th grade level (usually in math or science) that got them started. While the influence of this teacher led to an interest in science how this ultimately resulted in majoring in engineering was never as clear cut.

To provide for positive direction into engineering we sought to bring math or science teachers to the campus for a summer to work along side engineers in their research laboratories to get a clear idea of what engineers do. The teachers, in addition to strengthening their math and science backgrounds, then would serve as spokespersons for engineering in their respective classrooms. The program was directed towards the teachers, rather than students, because of the multiplicative effect obtained when the teachers bring their experiences back to all of the students they instruct. During the five years that the earlier program was in operation a total of 67 teachers from throughout the United States participated. Of the approximately 100 engineering faculty at Washington State University 19 have served as mentors (some multiple times) during the teacher's stay.

Basic Conduct of the Program

There are three primary goals for the program: 1) enhance the math/science skills of the teachers in the K-12 system, 2) increase the number of students interested in engineering as a major, especially amongst underrepresented groups, and 3) provide a means by which faculty at all levels who are concerned about this problem can communicate. The first goal has clearly been achieved. There have been concerns about the efficacy of the program in addressing the second and third goals, however. During this past year we took significant steps to strengthen the program to address these later two goals.

The basic structure of the program remained unchanged. One of the most important aspects of a successful activity is the recruitment of the teachers who will participate. We focused on science and mathematics teachers at the 6 – 12 grade level. We felt that it was important to have students exposed to engineering concepts as soon as possible in their education because majoring in engineering requires a strong mathematics background. Since the student's decision on the level of the mathematics classes they will be taking often occurs as early as the 7^{th} or 8^{th} grade having them exposed to engineering starting at the 6^{th} grade level seemed appropriate.

Our teacher recruitment activity starts in the fall, usually by hosting a booth at the state science teachers convention. This is followed up with ads placed in science and mathematics teachers newsletters, direct mailing to schools, and word-of-mouth by prior participants in the program. Interested teachers are asked to submit an application along with a supporting letter from their supervisor or principal. This latter aspect helps insure that the materials the teachers develop during the program will be used in their classrooms in the following academic year.

This program also seeks to include pre-service teachers so that they could learn both from the engineering faculty as well as experienced teachers. These were recruited by contacting science education programs at our own institution as well as other two- and four-year colleges and universities in the area.

Because one of our goals is to increase the number of students from underrepresented groups we also focused our recruiting efforts on selected schools from within the state. Greater recruiting efforts were focused on those schools with a higher than average enrollment of students from underrepresented groups, primarily Hispanic and Native American. The targeted schools were selected from lists supplied by our Mathematics Engineering Science Achievement (MESA) office as well as the Office of the Superintendent of Public Instruction for the state. We also have an additional source – a GK-12 program operated by Professor Denny Davis. The focus of this program is to place engineering graduate students into the classrooms of mathematics teachers in high schools serving areas with high percentages of students from underrepresented groups. By coordinating our efforts we have been able to bring teachers into our program, then have them go back to their schools and have graduate students work in their classrooms to make sure that engineering applications get stressed in the mathematics courses.

At the same time that the teachers were being recruited so too are the engineering faculty who would serve as the mentors for the teachers. Our intent was to have this program focus on engineering with an application to systems involving biological processes. This topic is both current as well as being of interest to the K-12 students. Six faculty are recruited for each summer session, with each faculty member mentoring two teachers, either an in-service and a pre-service teacher or two in-service teachers. The pairing of the teachers on any project is another way of increasing the interactions among the teachers, hopefully leading to longer term relationships.

Once the program actually starts there are a number of activities that have, at least partially, the intent of building a sense of camaraderie among all of the participants. The first activity in the program is a one-day meeting that was held in May involving the teacher participants and the faculty mentors. The purpose of this meeting is to introduce all of the participants to each other, firm up housing arrangements for the summer, distribute information on the research projects that would be available for the summer, and tour the campus and laboratories. All of the teachers, whether they were able to visit the campus or not, then were asked to return a listing of the top three projects on which they would like to work. By the end of May all teachers had been assigned projects. This allowed about two weeks for the teachers to communicate with each other, and with their mentor, prior to the start of the on-campus portion of the program. We found this two week period to be extremely important as it allows the teachers to start their preparation prior to arriving on campus. Furthermore, details such as housing arrangements, meals, parking, and continuing education or academic credits can be cleared up before the start of the program. This allows the full duration of the program to be focused on the research activity.

The on-campus portion of the program starts in late June so as not to conflict with the calendar for the K-12 schools. The duration of the on-campus activity is six weeks, ending in late July or early August. The duration was largely set by the desire to have the research activity last as long as possible, so that the teachers could make a meaningful contribution, but not so long as to conflict with the school year for either the K-12 system or the university. During the six weeks there is a daily, one-hour lecture covering basic concepts of engineering, grant writing, and teaching module preparation as well as some off campus visits to engineering businesses. A faculty member from our College of Education is involved in the module preparation to insure that all of the modules prepared address some aspect of the state standards in either mathematics or science. This is essential as the likelihood of modules that do not meet state standards being used in the classroom is very low.

The daily classroom session focuses on some current topic in which chemical engineering plays a central role. For example, after a brief introduction on how the various engineering disciplines developed, several class sessions focused on using sources other than petroleum for future fuel needs. As the starting point, we determined the total energy currently consumed by the transportation sector of the US. Then, using the first law of thermodynamics and the energy content of various alternative fuels (hydrogen, biodiesel, ethanol), the teachers computed the amount of these alternative fuels needed to replace petroleum on a joule for joule basis. Knowing how much of each fuel would be required allowed the teachers to determine the resource necessary to produce this amount (KW of electrical energy for the production of hydrogen from electrolysis, acres of canola for the production of biodiesel) of energy. Comparing these results with current levels of the resource then gave the teachers an understanding of the size of the task required to replace petroleum. As each of the various alternative sources was introduced the processes necessary to convert them from their raw form to a usable fuel were also discussed.

The research projects on which the teachers have participated cover a wide range of topics including: protein separations, sensors for water analysis, biomechanics, food processing, cancer treatments, and biocompatible materials. A question frequently asked is how cutting edge research in a university setting can be transferred to a middle school or high school setting. An excellent example of this is a project using lasers as a means of destroying cancer cells. The concept of the research project is that by selecting the correct wave length a laser beam will pass through the skin with little to no interaction. A dye could be injected into the body attached to an antibody that will interact only with the cancer cells. The dyes are selected such that they will interact with the laser. Thus, when the laser is focused on a particular spot of the body there will be no interactions except where the dye is concentrated (at the cancer cells). This produces a localized heating, thus killing the cancer cells.

This type of experiment is obviously beyond the scope of a middle school or high school. However, the underlying concept, that light of different wave lengths interacts differently depending upon the properties of the target, translates easily. The experiment that was developed consists of focusing a high powered halogen light through a colored filter onto a colored candle. For example, the light passing through a blue filter is mainly in the blue wave lengths. However, a candle that appears blue does so because it absorbs all other wave lengths except blue. Thus a blue candle exposed to blue light absorbs little energy. However a blue candle exposed to red light will absorb a great deal of energy and melt quickly. The equipment needed to conduct this type of experiment can be built for under $100 and used in virtually any classroom.

Indeed the teachers' originality can sometimes surprise the faculty. An earlier experience on a research project involving the biomechanics of the neck led the faculty member to suggest that it would not be possible to build a seven piece spinal column that would support the weight of a human head (about 8 pounds). A team of teachers took this as a challenge and developed a hands-on activity where students are asked to build a cervical spine composed of seven "vertebrae" (seven PVC end caps with pairs of eyelets attached to them) that will support a 1-gallon jug filled with water. The student may use rubber bands to hold the individual vertebrae together. After some trial-and-error most student groups are able to do this. What is most significant is that after building their neck the students can compare it to anatomical views of the ligaments, muscles and tendons in the neck. In almost all cases there is a close correlation between the placement of the rubber bands by the students and the actual arrangement of the supporting tissues in the human neck.

Social events, to build esprit-de-corps, have also been found to be essential to build the desired sense of community. These start with a welcoming picnic prior to the first day of the program. This is followed by a one-day team-building session using the ropes course at the university's Student Recreation Center. Later events (whitewater rafting, mountain biking) are attended by a majority of the participants and often their families. All of this is intended to form lasting relationships between the teachers and their mentors.

The primary mechanism for transferring engineering concepts and approaches back to the teacher's classrooms is the development of a teaching module, based upon their research experience, that the teachers can use in their classrooms. To aid in developing this module, and especially to insure their compliance with state standards in math and science, Don Orlich, from the Science, Mathematics, Engineering Education Center (SMEEC), conducted many of the classroom sessions during the latter portion of the program. To test whether the modules do in fact work well in a classroom setting local middle school and high school students, selected by the participating teachers, came to campus to test the modules during the last week of the on-campus portion of the program. This provides not only an opportunity to test the modules but also an opportunity to make contact with 25 – 30 students to spur their interest in engineering as a career.

Changes

While the program described above provided a strong basis for achieving our goals there were some areas of concern expressed by the teachers as well as the directors of the program. Foremost among these was the difficulty in maintaining contact between all of the parties involved. Feedback from prior participants often indicated a feeling of isolation; that while they had had an extremely beneficial experience they had a difficult time relating this to others in their school as well as a hard time implementing the activities they had developed with other teachers who had not participated in the program. A factor that contributes to this are the distances involved (at times as large as 400 miles). To counter this we attempted to recruit teams of teachers during this past summer's program. Four of last year's participants came as pairs from two different high schools. In another case two of the teachers invited to participate were selected because they came from neighboring school districts. In the future we will allow prior participants to return for a second year so long as they bring another teacher from their school or district.

We also implemented increased follow-up. Prior participants are offered an additional stipend to conduct workshops within their school or district, or at the state science teachers convention. Their faculty mentors are also encouraged to attend these events; their travel expenses will be covered as a further encouragement.

The hardest goal to assess is an increase in the number of students pursuing engineering as a major. Because the number of schools reached so far is a small percentage of the number in the state no statistically significant change can be (or likely will ever be) observed. Instead we have altered our assessment procedure to conduct pre- and post-exposure attitudinal surveys of the students after their teachers have used the modules prepared as part of this program. The assumption is that a positive change in attitude towards engineering will also translate into a higher percentage of the students enrolling in engineering.

Outcomes

There were three goals for this program that were mentioned earlier; improved skills for the teachers, increased interest in engineering by their students, and improved communications between the teachers and the faculty mentors. One of the major tools in achieving the first two goals are the teaching modules that are developed during the summer. Fifty-two teaching modules, available for use by any teacher, were developed during the initial phases of the program and are available on line at www.che.wsu.edu/home/modules/index.html. The modules developed under NSF RET funding are also available on-line at http://eerc.wsu.edu/SWEET/. These modules are often intended for multi-class period implementation so their length precludes presenting them here.

The impact of the program on the teachers has been evaluated using a survey completed by the teachers at the conclusion of the summer's program. The survey utilizes a 5-point Likert scale. When asked whether their participation would have no effect (= 1) or a strong effect (= 5) on how they teach math and science the average response was 4.2 ± 0.7. When asked whether their students would not (= 1) or would (= 5) benefit from the teacher's experience the average rating was 4.5 ± 0.6. The teachers reported that the program did expand their knowledge of engineering with a rating of 4.5 ± 0.6 (1 = did not, 5 = greatly expanded). Finally, when asked whether they would definitely not (= 1) recommend or would definitely recommend (= 5) this program to other teachers the average rating was 4.6 ± 0.6. Thus in terms of improved skills and attitudes from the teachers the impact of this program appears to have fully met its goal.

To assess goal #2, increased interest in engineering as a major, we developed an instrument to measure the student's attitudes towards engineering. This instrument is used in the classrooms of the participating teachers before and after they have used the modules they developed in their classroom. To date only one of the prior year's teachers has used these pre-and post-module surveys so our sample is still quite small (n = 30). While the students responses are generally quite positive the one question of particular importance asked "This type of science lesson makes me interested in engineering" (1 = strongly agree, 5 = strongly disagree). The pre-module average response to this was 3.00; the post-module average was 2.95. While this slight positive change (a lower score represents a more positive attitude towards engineering) is not statistically significant it does represent a change in attitudes in the desired direction. The class in which this module was used was also a senior level high school physics class. Thus it is likely that the students in this class were already considering pursuing college level studies in a science or engineering field so that exposure to the module developed as part of this program may have had a smaller effect than if the module had been used in a class with students who might be more undecided on their future plans.

Another interesting finding was the student responses on the survey given to them after the one-day testing session for the modules developed during the summer. In response to the question “This kind of science lesson makes me interested in engineering.” (1 = strongly agree, 5 = strongly disagree) the ratings ranged from 2.3 to 3.4. Those modules receiving the lowest scores (and therefore generating the greatest interesting engineering) were of the greatest interest in the popular press (fuel cells) while those receiving the highest scores were less directly connected to immediate problems (fluid mechanics for a lab-on-a-chip).

Maintaining communications between teachers and between teachers and mentors is one of the most difficult goals to meet. The interactions between the high school/middle school teacher and their university mentor have been valuable to both parties, as well as to the graduate students who inevitably get involved. High-end, Internet based technology has been developed to allow for communications between the teachers and their mentors but this has not been extensively used. Since this year represents the first time that teams of teachers have been recruited an assessment at the end of the current academic year will determine the impact of this strategy.

The most successful part of the program has been the involvement of underrepresented groups. Our recruiting efforts have focused strongly on schools with higher percentages of Hispanic and Native American students. As a result 19 of the 40 in-service teachers who have participated in the program have been from underrepresented groups (13 women, 4 Hispanic and 2 Filipino-American), including three from schools with large Hispanic enrollments and two from a charter school established by a nearby Native American tribe. Students from underrepresented groups were also actively recruited for the one-day module testing. Of the 115 students to participate in this activity 64 were from underrepresented groups (48 female, 13 Hispanic, and 3 African-American).

Conclusions

As a result of these past activities we have reached certain conclusions concerning activities, where laboratory experiences are used to convey the essence of engineering to K-12 teachers. Having the teachers work in pairs on their research projects is a necessity to prevent a feeling of isolation when working in the research laboratory. Teachers have a compatriot with whom they can share experiences, and they develop a close relationship with another teacher with whom they could interact in the future. This helps in implementing the module they have developed into their classroom as they will have a person with intimate knowledge of the module with whom they could talk. The close contact with another teacher was an especially valuable experience for the pre-service teachers. All of the teachers report that the program is highly valuable to them and does influence that manner in which they will present engineering concepts in their classrooms.

Preliminary results show a positive influence of this activity on the attitudes of students towards pursing engineering as a major. Anecdotal evidence suggests a meaningful influence but more student feedback is needed before the effect can be quantified.

Follow-up between teachers and between teachers and mentors is probably the hardest issue to address. This is particularly true for our situation because of the distances involved. The use of teacher teams and sponsored workshops to facilitate interactions is currently being evaluated

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