The Role of Engineering in Pre-College Education

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Introduction

As engineering educators, we often complain about the lack of preparation in math and science that our students exhibit when they first arrive on campus. Many who have been on the engineering faculty for a long time remark that the situation is worsening with time (or maybe it's just a sign of aging!). Increasing the number as well as the diversity of students who enroll in our engineering programs as well as improving the preparation of the students we do attract are also often cited as goals among engineering faculty/chairs/deans, but as engineering faculty we usually assume an attitude of "it's not my problem" when it comes to improving pre-college math and science instruction or addressing diversity issues. Michigan Tech has received funding for three major initiatives aimed at improving pre-college math and science instruction. In 1998 the College of Engineering received an Action Agenda grant with a portion of the funding earmarked for a workshop aimed at introducing engineering to pre-college teachers. In 1999 the Mathematics Department received a grant from the NSF under the GK-12 Teaching Fellows program to place Michigan Tech graduate students majoring in Science, Math or Engineering in local school districts. These graduate students assist teachers in the development of K-12 mathematics and science courses and programs that more closely align with what is recommended by state and national standards. Finally, in the spring of 2000 the College of Engineering received a significant grant from the NSF Collaborative for Excellence in Teacher Preparation (CETP) with three major thrust areas focused on bringing engineering applications into the pre-college classroom. This paper outlines the major activities from each of these grants as well as initial assessment results.

Initiative 1: An Introduction to Engineering Workshop for K-12 Teachers

The Rationale. Increasing the number of women and minorities who choose to study engineering has been a significant area of national endeavor for the past 15-20 years, however, despite a great deal of effort, the percentage of women who choose engineering has remained fairly static. Typically, less than 20% of the engineering students nationwide are women, although some engineering disciplines have a significantly higher proportion of women in their ranks. The number of minority students who choose engineering is depressingly low. Virtually millions of dollars have been spent in trying to improve this situation, with relatively minor gains. Many efforts have been aimed at bringing qualified high school women/minorities to campus for a summer session which is meant to serve as an introduction to engineering and to encourage these underrepresented groups to enroll in an engineering or technological field. Recently, new directions have been investigated which appear to be effective in getting to the roots of this complex problem. Some of the more promising projects for increasing the participation of women and minorities in engineer-

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ing is in working with high school and even junior high school teachers of math and science [1-5]. The approach taken by engineering faculty in these projects involves 1) working with the secondary teachers to improve their understanding of engineering and opportunities within the engineering fields, and 2) helping these teachers develop exercises suitable for introducing engineering to high school and even junior high school students. These efforts are seen as long-term systemic reform rather than a "quick fix" and therefore their true impact is unknown at this time. However, these programs have been very successful in educating teachers about a subject they have very little previous knowledge about--engineering.

The Michigan Tech Workshop. MTU has a long tradition of offering academic enrichment programs for precollege students. Seven programs bring over 1500 students and teachers to campus each summer for learning experiences of one to four weeks in duration. We will now extend these programs by working with secondary teachers to introduce them to engineering and the engineering disciplines (current summer sessions for teachers focus primarily on math and science--not engineering). We believe that these teachers are in a unique position to truly influence the lives of their young students by virtue of the fact that they have contact with them on an almost daily basis. The goals of this workshop are 1) to increase the understanding and appreciation that secondary math and science teachers have for the engineering profession, and 2) to work with secondary teachers in the development of "engineering" exercises suitable for delivery to precollege students. The workshop will be held on July 25-27, 2001 on Michigan Tech's campus in conjunction with our best practices conference for our GK-12 program (described in the next section) and will include hands-on activities designed to introduce teachers to the engineering profession. Discussion of pipeline issues will be a significant component of the workshop. Teachers will participate in engineering explorations in civil, environmental, chemical, computer, electrical, mechanical, materials, geological, and mining engineering. They will also receive training on a newly acquired scanning electron microscope that can be operated remotely via the internet. It is our intent that teachers who have received this training will be able to reserve time free of charge on the instrument during the 2001-02 academic year.

Initiative 2: Michigan Tech's GK-12 Teaching Fellows in Copper Country Schools

The Rationale. Preparation of students for the future is one of the principal goals of educational programs at all levels [6]. Reaching this goal, however, depends on keeping courses current and nowhere is that more difficult for educators than in the fast moving areas of science, mathematics and engineering. As K-12 educators seek ways to transform old courses in these fast moving areas into new state-of-the-art courses, the focus is on three tasks: changes in course content, improved pedagogy, and the use of technology [7]. Course changes often mean including new topics, sometimes interdisciplinary ones, and reducing the amount covered in order to allow for better learning. Improved pedagogy usually translates to one or more of the following: active student participation, a constructionist approach, the use of writing, and more projects. With increased use of technology comes a greater emphasis on visualization, the use of calculators, computers, and other equipment. Such technological tools, if properly utilized, can allow students to actively explore material and can extend learning opportunities to a wider variety of students. As K-12 teachers attempt to implement these changes so that their programs and courses are in harmony with state and national standards, the tasks at hand sometimes seem overwhelming.

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It is well documented by various state and national reports (*A Nation at Risk, The Mathematics Report Card*, etc.) that in this country many mathematics and science classes are being taught by teachers who are not certified in these areas. Teachers who do not have a thorough understanding of the subject matter cannot transfer enthusiasm for that subject to their students. It is therefore understandable why a large percentage of young people are turning off to mathematics and science: the instruction they are receiving is simply not exciting them to learn more. At Michigan Tech there is an unusually high percentage of students who are excited enough about mathematics and science to pursue careers in these areas. Currently, 88% of the university's student body (82% of the minority students) are pursuing degrees in mathematics, science, computer science, or engineering. It seems evident that graduate students from Michigan Tech have something special to share with students and teachers in K-12 schools.

Michigan Tech's GK-12 Teaching Fellows Program. This is a three year program which links higher education at Michigan Tech with primary and secondary schools in the Copper Country Intermediate School District (CCISD). Ten graduate students and 2-3 advanced undergraduate students are chosen each year for this program. To qualify students must be a U.S. citizen, majoring in mathematics, science, or engineering, be a full time graduate or advanced undergraduate student at Michigan Tech, and have their own car. A GK-12 fellowship includes a graduate student stipend of $18,000 per year ($10,000 per year for advanced undergraduate students), graduate student tuition and fees, and a $450 textbook allowance for graduate students. Needless to say, the competition is keen to get into this program. In return, each GK-12 teaching fellow spends a minimum of ten hours per week providing direct assistance to a teacher(s) in a local school and up to five hours per week preparing outside of the classroom. Local teachers submit mini-proposals describing ways that a GK-12 teaching fellow could help them create "cutting-edge" math and science programs in their school. The GK-12 fellows are then recruited and selected based on their abilities to carry out the work described on the selected teachers' proposals. The majority of students in the program for the past two years have been engineering students.

Broadly speaking, the goals of this program are 1) to improve the K-12 mathematics and science programs of schools in the Copper Country Intermediate School District, 2) to develop the professional talents of the participating graduate/undergraduate students and the participating teachers, and 3) to disseminate the best ideas and practices to K-12 mathematics and science teachers both regionally and nationally. Teachers frequently ask GK-12 teaching fellows to help develop math and science experiments/labs for the purpose of enabling students to actively engage in "doing" and learning the subject matter, to develop family math, family science and family computing programs, to help them apply the tools of technology in the classroom, to share their special academic interests with K-12 students, and to discuss career options within their fields of study. As university students in a K-12 environment, the fellows are automatically role models and can help motivate the younger students to consider careers in mathematics, science, and engineering. In order to help the beginning GK-12 teaching fellow develop his/her oral and written communication skills for work in the schools, all fellows take a 2-credit course in the fall semester titled "Communicating Science." In this course the fellows are taught to develop lesson plans and to develop age-appropriate oral and written materials. Fellows are also familiarized with the national and state standards and the Michigan Educational Assessment Program--these are some of the driving forces behind the course and program changes that teachers request. During the course, the fellows also help deliver Family Science, Family Math, and Family Computing nights at local

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schools. Dissemination of the best ideas and practices from this program is planned through a variety of avenues such as talks at the National Council of Teachers of Mathematics, the American Association of Science Teachers, the American Association of Engineering Educators, and the Michigan Computing Teacher's Association and such as written articles in professional journals and conference proceedings. In addition, we are currently planning a regional conference titled "Michigan's Upper Peninsula K-12 Teachers Conference on Mathematics and Science Education" to be held at Michigan Tech, July 23-27, 2001. This regional conference will feature talks on July 23rd and 24th by the participating teachers and fellows in the GK-12 Teaching Fellows Program on the best ideas and practices that they have created over the first two years of this program. A sampling of talk titles for this conference include: "Elementary Science Labs--Hands On," "A School Forest", "Family Fun Night," "Introducing the CBL into Algebra I," Think Quest--A Web Page Design Competition for 4th-6th Graders," and "Mentoring MultiMedia Presentations." The intended audience for this conference is certified K-12 math and science teachers.

Initiative 3: Engineering Applications in Pre-College Education

The Rationale. Certainly one of the dominant problems facing the recruitment of scientists and engineers are a direct result of the problems facing our public school system. Estimates indicate that nearly 40% of math and science teachers nationwide have neither the training nor the certification to teach in those disciplines. This situation is magnified in urban schools where the number of untrained and uncertified math and science teachers is approaching 70%. This problem is compounded by the fact that fewer teachers trained to teach math are actually teaching math. For example, in Oklahoma the SREB reports that only 54% of college graduates trained to teach math between 1994 and 1996 were teaching math in 1996. Finally, a report published by the American Association of Colleges of Teacher Education, finds fewer and fewer high school students interested in the teaching profession. The answer to the intertwined problems of fewer engineers and scientists, fewer women and minorities entering engineering, and the quantity and quality of math and science teachers may lie in identifying new sources and methods for producing this nation's teachers. Simply put, our traditional sources are limited. We need to find new sources for new teachers. We believe that a major untapped resource in the area of math and science education may lie in our colleges and schools of engineering. In our current education structure, the historic distinctions between colleges of engineering and teacher education have fostered systems that make it very difficult for someone who is trained as an engineer to consider a profession in teaching. It is rare to find someone who is educated as an engineer with all of his/her mathematics and scientific preparation also prepared to contribute to the nation's teaching force. It is rare to find faculty in a college of engineering actively participating in broad based teacher education. Yet engineering students do have an excellent mathematics and scientific preparation in addition to a unique insight into the application of math and science. Engineers and engineering students could help to alleviate this crushing national problem.

We believe that there are many students in our engineering programs who would like to take their engineering expertise and apply it to a career in teaching. A dual engineering and teacher certification degree program would provide more career choices for engineering majors and provide an alternative for those who after 2 or 3 years of studying engineering, decide that they really don't want to be engineers after all. In fact, Michigan Tech conducted an internship program for four years with a total of approximately 80 students. The students who participated in the program were mostly third year engineering students (some were in their second or fourth years) who had expressed disenchantment with their chosen career choice (engineering) and were thinking about leaving the profession. These students were paired with local K-12 teachers and were paid for 10

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hours/week to assist the teachers in science and math instruction and the development of suitable materials. At the end of their internship, about half of the students each year decided to pursue a teaching career and several other students expressed an interest in working for a few years in industry and then going back to school to receive teacher certification.

The Michigan Tech CETP Project. This project focuses on improving pre-college math and science instruction by the implementation of three thrust areas - 1) Integrating Engineering into Teacher Education, 2) a Bachelor of Science in Engineering and Teacher Certification degree program, and 3) Professional Development through Engineering Applications for current teachers.

1) Integrating Engineering into Teacher Education focuses on developing a collaborative model of teacher education where faculty within the College of Engineering, the School of Technology, and the Department of Education at Michigan Tech develop and deliver courses suitable for future K-12 teachers. The goal here is to introduce preservice teachers across disciplines to engineering concepts and the engineering problem solving method. For this thrust area a two tiered approach will be used. First, a new course titled "Engineering Applications in Math and Science" will be developed and available for all teacher education students in all disciplines at Michigan Tech. This course will be developed and offered by engineering and engineering technology faculty in combination with education faculty and will be a practical course that will provide prospective teachers with specific types of learning activities they can apply in the classroom to foster fundamental engineering concepts linked to various disciplines and to national math and science education standards. Beyond a course in Engineering Applications for all teaching specialities, a new teaching and certification minor called Technology and Design will be developed at Michigan Tech. This minor will be suitable for students who are pursuing teaching certification in secondary math or science. Courses for this minor will be developed as *engineering* courses for non-engineering majors. According to state of Michigan standards, a valid minor requires 24 semester credits of course work and the courses for the minor must address "the ability to use and apply technology, understand the issues raised by the use of technology, and appreciate the significance of technology." Students who complete the necessary coursework for this minor will be certified to teach pre-college technology courses.

2) The *Bachelor of Science in Engineering and Teacher Certification* degree program developed through this project will allow a student to complete an ABET accredited engineering degree and at the same time complete teacher certification in math, technology and design, and one of the sciences. With this project we will develop and administer a program whereby students complete a Bachelor's degree in engineering and receive teacher certification all within a standard 4-year program of study. The degree will be offered through our Bachelor's of Science in Engineering (BSE) program, which is fully accredited by ABET. The program will be designed as a four year program so that students can enroll in it from the start of their college careers, but it will be flexible enough to accommodate students who wish to transfer into it after 2-3 years in a traditional engineering program at Michigan Tech. Thus, after four years of study (including student teaching) a person could graduate with a fully accredited engineering degree and be certified to teach at the secondary level. This BSE degree will be linked to our Master of Engineering (MEng) program so that students could choose to spend a fifth year at Michigan Tech ending up with an ABET accredited BS, a graduate engineering degree, **and** teaching certification.

According to current ABET requirements, an accredited engineering degree must consist of a

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minimum of: 1) 32 credits of Math and Science, and 2) 48 credits of Engineering Science and Design. The minimum number of credits for teaching certification in the state of Michigan is 26 credits (including student teaching). Michigan Tech also has a new General Education program for a total of 25 credits (this more than meets the ABET General Education requirements). Altogether, this means 131 total credits to graduation for students enrolled in the program which should be feasible for a four-year program.

3) Finally, building on our previous successes, and to support the professional development of teachers the *Professional Development through Engineering Applications* thrust will be used to develop a series of summer workshops for current math and science teachers. Through participation in these activities and other coursework, teachers will be able to complete coursework required to move from a Michigan Provisional Teacher Certificate to a Professional Teaching Certificate. In addition, this coursework will be an integral part of a master's degree program that we are in the process of developing at Michigan Tech (final approval of the program is currently pending). The master's degree program, titled Master of Science in Applied Science Education (MS-ASE), has the following features: 1) a required 12-credit engineering core, 2) a required 6-credit education core, 3) a required industry internship, 4) elective credits in applied science or mathematics, and 5) a capstone research project. The engineering core consists of three, 2-week summer intensives--The Engineering Process, Engineering Applications in the Physical Sciences, and Engineering Applications in the Earth Sciences. We will offer the first of these summer intensives in July/August 2001.

Preliminary Feedback and Assessment

Initiative 1: An Introduction to Engineering Workshop for K-12 Teachers. The workshop promised for initiative 1 will be held in conjunction with the summer conference on best practices from initiative 2 scheduled for the summer of 2001. For this reason there is no assessment data to report at this time.

Initiative 2: Michigan Tech's GK-12 Teaching Fellows in Copper Country Schools. Since this is a three-year program and we are currently in the second year of the program, the feedback and assessment information reported here is based only on the first year of the program. Longer term objectives obviously cannot be evaluated until later in the program. Project objectives supporting the overall goals of the program are listed below with current assessment results or the status of the assessment mentioned for each objective.

Objective 1. For schools and students directly affected by the program, Michigan Educational Assessment Program scores in the areas of mathematics and science will improve over the three-year period. The data needed to assess the accomplishment of this objective will not be available; until the third year of the project.

Objective 2. For courses directly affected by the program, these courses will more fully align with national and state mathematics and science standards. Twenty participating teachers completed an end of the year final evaluation form. On Part A of this form teachers were asked to check off the Michigan Mathematics, Science and/or Technology Content Standards that their project addressed. There were 15 standards listed for mathematics, 15 for science and 6 for technology. Of the twenty teachers who responded, 17 checked one or more mathematics standards addressed

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by their projects, 18 checked one or more science standards being addressed by their projects and 16 checked one or more technology standards being addressed by their projects. Across all 20 teachers responding, the average number of math, science, and technology standards reportedly being addressed were 5.25, 4.2, and 2.25, respectively.

Objective 3. Participating graduate and undergraduate students will improve their communication and teaching skills and become more aware of ways they can contribute professionally to local schools. During the Communicating Science course, GK-12 teaching fellows were pre- and post-tested on a 13 item self assessment measure and asked to respond to each question using a scale from 1 to 10 (1 = strongly disagree, 5 = neither agree nor disagree, and 10 = strongly agree). On Question 1(I am confident in my current ability to effectively communicate what I know to K-12 students and the community.), the pre-test average was 7.0667 and the post-test average was 8.6667. The average gain score (n=15) of 1.6 was statistically significant (t =3.511) at the level $p<0.005$. On Question 2 (I believe it is an important civic responsibility to help educate children and adults in the local community about the relevance of science in their everyday lives.), the pre-test score was 8.7333 and the post-test average was 8.6000. The difference in these two averages (n = 15) was not significantly different from zero. However, it is encouraging to note that on a scale from 1 to 10 the fellows' average scores indicate strong support of this statement both before and after the Communicating Science course. It is also worth noting that one of the GK-12 teaching fellows has decided to become a K-12 science teacher as a result of his experiences in this program. On Question 3 (I enjoy teaching.), the pre-test average was 7.1333 and the post-test average was 8.7333. The average gain score (n=15) of 1.6 was statistically significant (t = 3.595) at the level $p<0.005$. On Question 11 (As a professional, it is important for me to have good oral and written communication skills.), the pre-test average was 9.6429 and the post-test average was 9.7143, indicating strong support of this statement by the fellows. The average gain on this question was not significantly different from zero ($p<0.10$). The average gain scores on the remaining 9 statements on this self assessment measure were not statistically significant.

Objective 4. As a group, the participating teachers will become more knowledgeable about both the content and application of science, engineering and technology. Teachers were specifically asked on Part B of the final evaluation form about their increase in knowledge in content areas and about applications. In response to the question, "Have you as an individual become more knowledgeable about a content area as a result of the GK-12 teaching fellow's work in your school?" fifteen teachers responded "yes", five responded "no", and nobody responded "uncertain". Comments regarding the content area where their knowledge had increased included "I now understand the content standard on Ecosystems" and "More knowledge about DNA lab procedures." In response to the question, "Have you as an individual become more knowledgeable about applications as a result of your GK-12 teaching fellow's work in your school?" twelve teachers responded "yes", three responded "no", and five were "uncertain". Examples of new applications with which the teachers are now familiar included "Applications of DC circuits," "Applications of the Calculator Based Ranger," and "Applications of Netscape."

Objective 5. A greater number of professional development opportunities for local teachers will be made available as a result of increased communication between university faculty and local teachers. As a result of the work of two GK-12 fellows in computer science and their department chair, a week-long workshop titled "Computing in the Classroom" for K-8 teachers was offered

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last summer, June 19-23, 2000. Twenty-six teachers attended this workshop. One cooperating elementary school teacher attended a 2-day Family Math training program with the Communicating Science instructor. One secondary chemistry teacher attended the NSF GK-12 Principal Investigator's 2-day conference in Washington D.C. last March. One elementary school teacher and her GK-12 teaching fellow spent one month last summer in Malaysia visiting schools and universities there as part of the global component of this program. Further, all participating teachers will be giving talks over their best ideas and practices as a result of the GK-12 program at this summer's conference, July 23-24, 2001.

Objective 6. Best ideas and practices from this project will be disseminated regionally through a summer workshop for Upper Peninsula K-12 mathematics and science teachers and nationally through mathematics and science education conferences. Since the summer workshop is scheduled for July 23-24th, 2001, there is no assessment data to report on the conference at this time. Talks regarding the best ideas and practices and other general information from Michigan Tech's GK-12 Teaching Fellows Program have been accepted at meetings of the National Council of Teachers of Mathematics (NCTM), the American Association of Science Teachers (AAST), the American Association of Engineering Educators (ASEE), and the Michigan Association for Computer-related technology Users in Learning. Writing articles for mathematics education, science education, and engineering education journals is just beginning.

Initiative 3: Engineering Applications in Pre-College Education. The grant activity has just started (June 2000) and as such we are primarily in the planning stages for this program. We have hired an external evaluator for the project who has developed a detailed assessment plan that we will fully implement. We also have upcoming meetings scheduled for a locally-based Advisory Committee and for a National Visiting Committee.

Conclusions

In order for our children to be able to cope in our increasingly technological society, it is vitally important that they have well-grounded math and science skills. Engineers and engineering faculty can and should play a critical role in improving math and science instruction at all levels. We believe that the programs initiated at Michigan Tech are a step in the right direction.

Acknowledgement

The authors would like to gratefully acknowledge the National Science Foundation for their support of this work through grants No. EEC-9872533, DGE-9979572, and DUE-9953189.

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