

DIVERSITY IN K-12 INITIATIVES TO ATTRACT A DIVERSE POOL OF ENGINEERING STUDENTS

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Abstract - Faculty and students at Clarkson University have developed a 10-week unit for middle school students to increase their awareness and aptitude for engineering. The unit, entitled "Engineering for the Environment," challenges students to reduce solid waste from their community by reusing the waste in the form of a valuable material. Science, engineering and math are integrated to help students learn to transform biodegradable materials into compost and to incorporate non-biodegradable materials as an aggregate in concrete. This unit shows young students that there is a wide diversity in the nature of work done by engineers, and that engineers can indeed help the environment and society – messages that are particularly important for young girls. The Engineering for the Environment curriculum will be incorporated into Project Lead the Way's middle school curriculum to balance existing units that focus on mechanical and electrical aspects of engineering.

Index Terms – middle school, environment, girls, engineering

INTRODUCTION

Through partnerships with the National Science Foundation, the GE Fund, and several local school districts, faculty and students at Clarkson University developed a 10-week unit for middle school students entitled *Engineering for the Environment* to increase their awareness and aptitude for engineering. The project-based approach we've used replicates our success in utilizing project-based learning to educate multidisciplinary undergraduate teams.

The new middle school curriculum is based on the concept of using diverse teams and applying basic problem-solving techniques to understand an environmental problem and coalesce fundamental science with societal, ethical and other constraints, prior to assessing and implementing a solution. Environmental topics readily afford high-touch and visual applications of engineering in a problem situation familiar to middle school teens, making the subject matter a good platform for further exploration of more abstract

concepts within engineering and underlying application of fundamental skills such as algebra and math computations.

The *Engineering for the Environment* curriculum will be disseminated to middle school students across the country as one unit in the Gateway-to-Technology Program offered through the *Project Lead the Way* (PLTW). PLTW is a not-for-profit organization partnering with public schools, organizations in the private sector, and higher education institutions to increase the number and quality of engineers graduating from the U.S. educational system. They currently train teachers and provide curricular materials for approximately 50,000 middle and high school students in over 500 school districts.

Still in the early stages of development, PLTW's new middle school component – *Gateway to Technology* – includes modules on Design and Modeling, Magic of Electronics, Science of Technology, and Automation and Robotics. These units integrate math, science and technology and provide an introduction to the latest advances in some engineering fields. However, they lack a strong connection to the importance engineering can have on the quality of the environment or human lives. Subsequently, the current configuration of PLTW *Gateway* courses falls short of attracting proportionate numbers of talented women and minorities, whom evidence suggests are more attracted to holistic approaches to problem-solving and service-oriented commitments.

BACKGROUND

Women and minorities continue to be dramatically underrepresented in engineering and other quantitative fields [1]. Research has shown that while women are adequately prepared to enter these fields, they choose not to due to their lack of interest or knowledge of career opportunities [1]. As described in detail below, both the content of the engineering discipline and the nature in which it is introduced affect a young woman's choice about engineering and other quantitative careers.

The breadth of disciplines within engineering is critical. Amazingly high enrollments of undergraduate women in engineering fields such as bioengineering (40%) and

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environmental engineering versus mechanical and electrical (14%) [2] suggest that women are more interested in careers based on life sciences that are perceived to be beneficial to humanity. Haines et al. [3] reiterated this premise. These authors demonstrate gender advantages and disadvantages based on four key factors occurring during a student's K-12 education that become indicators of later choice and success in engineering. Women have more confidence in biology preparation, chemistry interest and mathematics, whereas males experience greater ease and confidence in physics. The study further demonstrates that female students report more mentors influencing their decision to pursue engineering than their male counterparts. Similar findings were reported in a study of women in non-traditional, technology-related professions, where many women reported that their career choice was influenced by an encouraging teacher or professional role model [4].

Relevance is also important. A study conducted at Worcester Polytechnic University found that many women capable of pursuing engineering careers opt for a liberal arts college instead, because they perceive it as offering a more "interesting or relevant environment" [5]. Indeed, relevance of their engineering coursework to the "outside" world is a large factor in keeping women enrolled in engineering [6]. Emphasizing the usefulness that science and engineering has for improving peoples' lives can persuade a wider range of young students to study these fields [7].

A holistic or project-based learning (PBL) approach to engineering and science tends to make quantitative subjects more "female friendly," by bringing *relevancy* and *connectivity* to their coursework and to the outside world. The benefits of this approach are not limited to female students. Indeed, much of the education reform efforts of the 1980s and 1990s were aimed at bringing an integrated, hands-on approach to the teaching of math and science, to make these subjects more relevant and tangible [8,9,10,11,12]. Among the action recommendations in ACTION FOR EXCELLENCE [11] is a statement that schools should "... serve better those students who are now unserved or underserved." These underserved groups include women and minority students, as well as other students at risk, who are less apt to thrive in a lecture-based classroom environment.

Generally speaking, women tend to be interested in relationships and interdependence. They prefer to view an experiment in relation to the research project as a whole, a branch of science as it relates to other disciplines. Emphasizing the usefulness that engineering has for improving peoples' lives can persuade women to pursue engineering [7]. While boys tend to excel and dominate in competitive learning environments that emphasize whole-group instruction, girls' achievement is enhanced (at no hindrance to boys) by hands-on cooperative strategies. A positive, nurturing hands-on experience in science and engineering, within a same-sex peer group and with role

models, will alleviate feelings of isolation and improve attitudes toward these fields.

Experiential and interdisciplinary learning techniques are gaining a foothold in engineering education [13,14,15,16]. Trends in teaching with problem (or project)-based learning (PBL) concepts require students to tackle a problem. The PBL approach is consistent with National and state standards for math science and technology at the middle school level, as well as criteria that have recently been implemented by the Accreditation Board for Engineering and Technology (ABET). Interdisciplinary team-based projects and project-based learning are shown to improve the understanding of basic concepts and to encourage deep learning, creativity, and a broader knowledge base, as well as developing team-work and communication skills, all of which are goals of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology [8].

In order to attract more women into engineering, schools need to provide experiences that teach girls the wide-spread usefulness of engineering to social, environmental, medical and other people-related needs. PLTW's current Gateway-to-Technology units integrate problem solving and team-based experiences that are approaches to increase the interest of girls, yet they focus predominantly on engineering projects that are physics based, which favor the strengths of males. It is our objective to provide curricular content in the science and technology classes that is perceived as more relevant to girls and that is based more on the integration and use of biology or chemistry fundamentals. Based on the literature reviewed above and our own experience with the interest of female engineering students in environmental engineering, we expect that providing middle school students with a broader understanding of the range of activities and careers within engineering will increase the interest of middle school girls in these fields.

PROGRAM DESCRIPTION

Clarkson University has been working with four schools in Northern New York State to develop a curriculum that uses environmental problem solving as a means of introducing engineering problem solving skills and the fundamental math, science and technology concepts required to solve these problems. The concept of *project-based* learning incorporates a "big-picture" approach to enhancing science, math and technology knowledge, critical thinking, and problem solving skills. Project-based learning requires students to understand a problem, with all of the fundamental science, societal, ethical and other constraints, prior to assessing and implementing a solution.

Graduate and undergraduate science and engineering students from Clarkson work with middle school science and technology teachers at our local partner schools to develop

the curriculum. Following the definition of a project statement, Clarkson students search for and develop suitable activities and link them with science or technology content that is required in the New York State standards. Teachers then attend a workshop with some of the students to refine these ideas and mold them into a logical and complete 10-week unit. Clarkson students join the teachers in the classroom 2-3 days per week to help teach the curriculum. Depending on the teachers' overall curricular plan, a 3 or 7-week portion or the entire 10-week curriculum is taught in the technology classroom. Related lessons are taught in parallel in the science classes at two of our partner schools to help show the integration and importance of basic science concepts in the development of engineering solutions.

The curriculum at Potsdam Central School was supplemented with a program that provided extra out-of-class opportunities for 8th grade girls to interact in mentoring activities with female Clarkson engineering students. In previous years, our interaction with this class has included a separate program - just for girls - where they were introduced to our curriculum in a classroom separate from the boys. In the fall of 2002, the mentoring activities were provided for the girls, but the entire co-ed class participated in a three-week section of our environmental problem-solving curriculum (see next section). Mentoring activities for girls included leadership and team building, a fun solid waste reuse project – papermaking, a game night for social interaction, and a dinner to introduce the 8th grade girls to a broader range of women engineering students, their thoughts on factors that motivated their decision to study engineering, and their perceptions of their career choices.

ENVIRONMENTAL PROBLEM SOLVING CURRICULUM

The 10-week curriculum that has been developed through this program challenges students to integrate materials found in our solid waste in a usable product. A four-section unit takes the students through a classic problem solving approach, beginning with understanding the problem and finishing with the production and assessment of the value of their finished products. The general concepts covered in the curriculum are outlined in Table I. In the first unit, students learn about the problems and current solutions for our solid waste problems. A standard problem solving approach used in middle school technology textbooks is introduced in this unit and used repeatedly throughout the curriculum (Figure 1). A series of brainstorming activities lead students to choose high quality soil and concrete as products we can make from biodegradable and non-biodegradable solid waste, respectively. The next two units enable students to learn more about these solutions and to complete the problem solving method:

TABLE I OUTLINE OF CONCEPTS AND PROJECTS INCLUDED IN THE ENVIRONMENTAL PROBLEM SOLVING CURRICULUM	
1. Introduction to Solid Waste Problems & Solutions	<ul style="list-style-type: none"> • Definitions and statistics about solid waste generation, including an historical perspective of the impacts technology and society have had on waste generation. • Understanding how nature handles solid waste • Current technological solutions: Landfills, 3-R's • Problem solving approach • Defining products we can make from solid waste
2. Vermicomposting for Biodegradable Wastes	<ul style="list-style-type: none"> • Biodegradation • Scientific method • Engineering a system to improve rates – Vermicomposting • Using the Web as a research tool • The design process – Vermicomposting bins <ul style="list-style-type: none"> ○ Drawing ○ Assembly and flow charts ○ Construction • Implementation – Technologies based on living systems – the constraints of keeping it alive
3. Non-biodegradable Wastes as Aggregates in Concrete	<ul style="list-style-type: none"> • Concrete basics • Material properties • Making Concrete & Safety • Forces & Stress • Testing for engineering decisions – Breaking cylinders • Weighted objectives table for engineering decisions • Concrete Product Production and Evaluation
4. Marketing Our Product	<ul style="list-style-type: none"> • Introduction To marketing • Importance of communication in engineering • Understanding the value of our products • Developing & presenting a marketing plan

- construction and implementation of vermicomposting bins, which employ red wiggler worms to substantially increase biodegradation rates,
- production of benches or stepping stones from concrete made with waste materials as aggregate.

Through the completion of these projects, students learn the value of experimentation for providing design parameters (the extent of biodegradation) and a basis for engineering choices (the strength of concrete with different waste aggregates). A unit on marketing provides closure for the

entire curriculum and emphasizes the need for engineers to communicate their findings and understand the market value of products they design. The inclusion of vermicomposting provides a means of integrating life science into our technological solution.

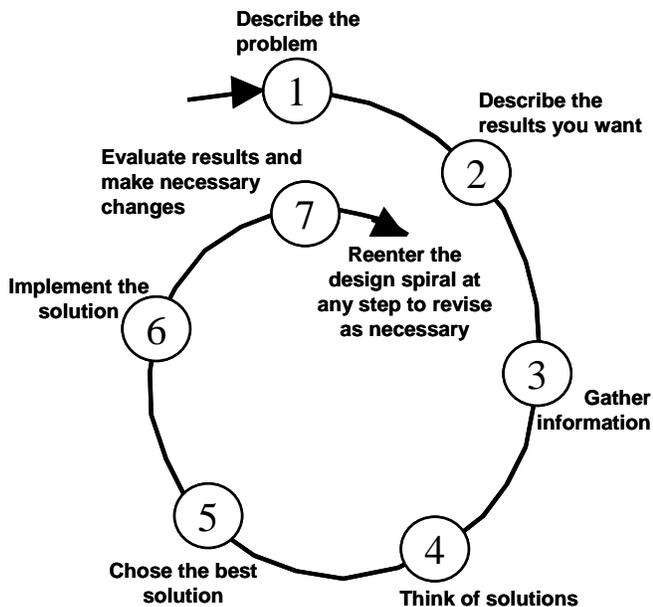


FIGURE 1
AN ITERATIVE APPROACH TO ENGINEERING PROBLEM SOLVING
(ADAPTED FROM [17])

The types of skills covered in our curriculum are directly related to the applicable educational standards in New York State [17-18]. The New York State Learning Standards for Mathematics, Science, and Technology include: 1) Analysis, Inquiry, and Design; 2) Information Systems; 3) Mathematics; 4) Science; 5) Technology; 6) Interconnectedness of Common Themes; and 7) Interdisciplinary Problem Solving. Our program addresses several aspects of the technology standards and is especially strong in addressing the “extended process skills” (Standards 1, 2, 6 and 7). As an added value, this curriculum also addresses several performance objectives associated with the science (4) and math standards (3).

ASSESSMENT

On-going assessment activities conducted to date have included a science interest and attitude survey, as well as focus group discussions with teachers and students. Current efforts also include collection and analysis of data related to student grades, state exam scores, and choice of classes as they enter high school. Preliminary results from the surveys and focus groups are included here. The more comprehensive and quantitative analysis of the impact of this program is incomplete.

Dr. Timothy Schwob developed the middle school survey based upon the work done by Aikenhead et al. [19], Gardner and Tamir [20], and Skinner and Barcikowski [21]. The attitude and interest scales they developed were adapted as appropriate for this program. The survey includes four components:

- preferred learning styles
- confidence inventory
- perceptions of the ability of science and technology to solve societal problems
- career preferences

Table II lists some of the statements from the survey that relate to the students’ perceptions of the ability of science and technology to solve problems. Students choose Strongly Disagree, Disagree, Agree, or Strongly Agree to identify their thoughts on each of these statements. The analysis of pre- and post-survey results related to these statements will help us identify if students, and girls in particular, have a broader view of the types of problems engineers can solve. At this point, analysis of only preliminary data has been completed. The preliminary analysis included surveys that were distributed in one point in time. Sixth grade students had not previously been involved in our program; most of the seventh graders had Clarkson students in their classroom for one year, and most eighth grade students were in our program for two years. Data were compared among schools and between grade levels and gender. There are not sufficient numbers of students of color in any of our schools to enable us to break them into a separate group for analysis. We had a control group at Potsdam Central School where we worked with only two of the six 7th grade science sections. Some interesting highlights from the survey include:

- girls were more interested in careers as science and

TABLE II EXAMPLE STATEMENTS FROM MIDDLE SCHOOL SURVEY - STUDENTS’ PERCEPTIONS OF THE RELEVANCE OF SCIENCE AND TECHNOLOGY
<p>I believe that science and technology ...</p> <ul style="list-style-type: none"> • can help me to figure things out and decide if something (for example, an advertisement) is true or not • can fix pollution problems • cannot help me make better everyday decisions because science classes have nothing to do with my life or the real world • can help to resolve social problems such as overpopulation • can improve health by maintaining cleanliness and controlling drinking water supply

math teachers and also tended towards an interest in biological sciences

- there was less interest in science and technology careers among older students
- students in all groups were very consistent with 55% selecting learning choices that involve experimental and hands on versus passive learning styles
- girls tended to rate group work activities higher and are more confident in this area than the boys
- there was very little difference in the overall confidence levels between the girls and boys
- there was no real difference between the responses of students from Potsdam Central school that were in our classes and those in the control classes
- there was no real difference between boys and girls in their perceptions of the types of problems science and technology can solve. Both recognized that these disciplines could fix many specific problems (e.g. provide clean water), but had less confidence that engineers could solve social problems.

At this point, it is premature to attribute any of these findings directly to our program. Many of the points (e.g., girls more interested in biology, and the decrease in interest in science and technology with increasing grade level) are consistent with current understanding of middle school students in general. Further longitudinal analysis that tracks how an individual changes will allow us to better assess the impact of our program in particular on attitudes and achievement in science, math, and technology.

The direct impact of our program on girls can be assessed best by analysis of the program for 8th grade students at Potsdam Central School that included an additional mentoring program for the girls in two of the six classes. Focus group discussions were conducted by Dr. Mary Graham to determine any differences in attitudes or confidence between male and female students in the Potsdam classes. Input from the teacher was also valuable in this assessment.

The middle school teacher felt that our program would encourage students to pursue science and technology careers. Many participants indicated that they would consider engineering as a career; a few indicated that they did not want to pursue an engineering career. The reasons offered for not pursuing an engineering career focused on stronger interests in other areas and a dislike of math. Almost all participants felt that they had the skills and abilities to do math and to study engineering, and they noted that it was up to the individual to invest the necessary time and effort.

There is some initial evidence that the combination of out-of-class mentoring for girls, together with classroom activities that bring Clarkson women engineering students in contact with both male and female students may be more effective than a separate pull out program for girls: (1) the

relationships that the girls formed with the Clarkson mentors appeared to bolster the girls' confidence in doing technology projects in a co-ed setting, (2) the presence of women engineers in the classroom reinforced to girls that engineering and technology careers could be done by women, (3) the presence of the Clarkson women seemed to change the class dynamic in that the boys may have felt a little less comfortable since their technology class is usually taught by a man, and they consider technology to be a subject about which boys know more, and (4) the boys were able to observe the progress and success the girls were having in technology. Further quantitative analysis comparing the girls in Potsdam who have the extra mentoring component should help identify the value of this component of our program.

SUMMARY

An on-going program that brings an environmental problem-solving curriculum to middle school students has been designed to help students – especially girls – understand the breadth of activities in scientific and engineering careers. The program includes three components that are expected to make it more “female friendly.”

- project-based with relevant environmental problems
- technology applications based on life science
- mentoring for girls (in one school)

The curriculum has been well received by middle school teachers and students. Preliminary assessment suggests that the mentoring component at Potsdam Central School is important for the confidence and participation of girls in the technology classroom. It is premature to draw any further conclusions regarding the effectiveness of our environmental problem-solving curriculum on the interest of either male or female students in science or engineering careers.

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