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Teaching Teachers to Teach Engineering

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ABSTRACT

Massachusetts is leading the integration of engineering into K-12 education by adopting a statewide science and technology/engineering framework. To meet the need for teachers who can deliver this curriculum, we have assembled an interdisciplinary team from Smith College and Amherst Public Schools to design a workshop for pre-service teachers of all grade levels and subject areas. Through this workshop, we intend for students to increase their familiarity with the engineering field and state frameworks, learn about the engineering design process, develop an understanding of how engineering can be used in classrooms of many disciplines, and develop an understanding of the relationship between engineering and the liberal arts. This paper describes how the curriculum was implemented through a one-week workshop for 21 education students, representing a wide range of disciplines and grades. In this workshop, we used a variety of hands-on activities intended to meet the needs of each learner. Activities included laboratory explorations of content knowledge and delivery according to grade level, application of the engineering design process through redesign and design projects, student teaching of engineering topics, and team development of interdisciplinary engineering curricula. Pre- and post-workshop student surveys indicate that the intended learning outcomes of the workshop were met. The experience positively impacted how students viewed engineering and their intentions for including it in their teaching.

INTRODUCTION

> "Most people think that technology is little more than the application of science to solve practical problems…They are not aware that modern technology is the fruit of a complex interplay between science, engineering, politics, ethics, law, and other factors. People who operate under this misconception have a limited ability to think critically about technology—to guide the development and use of a technology to ensure that it provides the greatest benefit for the greatest number of citizens."
>
> -- National Research Council (NRC), 2002[1]

Although engineering traditionally has been taught exclusively at the college level, there is increasing nationwide interest in making engineering a part of pre-college education. For

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example, the National Research Council[1] reports that "the natural place to begin is in grades K-12, when all students could be guaranteed a basic familiarity with technology and could be encouraged to think critically about technological issues." By becoming the first state to adopt a statewide framework for K-12 technology/engineering education, Massachusetts is leading our nation in recognizing the need to integrate engineering into K-12 education. Beginning in 2002, the *Technology/Engineering Framework*[2] has become a major mandatory component assessed by the Massachusetts Comprehensive Assessment System (MCAS) Test. The International Technology Education Association has also published standards specifying what students should know and be able to do to be technically literate[3]. Through implementation of the Massachusetts or ITEA standards, students will increase their technical literacy by learning concepts and processes that are fundamental to technology and engineering. If properly implemented, the *Framework* also has the potential to encourage the use of engineering as an instructional tool, with numerous benefits:

- motivating the study of mathematics and science by providing relevant and tangible applications;
- improving problem-solving abilities through learning and applying the engineering design process;
- providing a natural context for project-based learning; and,
- supporting the integration of seemingly disparate subjects as students learn to apply technology/engineering in a way that best serves humanity.

Although the *Technology/Engineering Curriculum Framework* now exists, few teachers, curriculum coordinators, or administrators throughout Massachusetts are familiar with technology/engineering content or how it can be implemented in the classroom. No immediate solution is available through pre-service teacher education—exemplified by the fact that few programs offer accreditation in technology/engineering. How can engineering be implemented more widely and effectively in K-12 contexts? Both pre-service and in-service teachers need opportunities to learn the new concepts, skills, and pedagogies required to teach technology and engineering.

The Picker Engineering Program and the Department of Education and Child Study at Smith College have teamed with the Technical Education Department at Amherst Public Schools to design a curriculum that will help K-12 teachers integrate engineering into their future classes. This curriculum was first implemented in a one-week workshop in July 2003 to a class of 21 education graduate students (19 women and 2 men) at Smith College. The workshop was required for all education graduate students, so pre-service teachers of grade levels from elementary school through high school were represented. Subject disciplines for pre-service middle and high school teachers included mathematics, biology, English, art and history.

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Our intended learning outcomes of the workshop were the following.

The student will:

1. become familiar with the field of engineering;
2. become knowledgeable about the *Massachusetts Science and Technology/Engineering Curriculum Framework*;
3. develop a basic understanding of the engineering design process;
4. develop an understanding of engineering as a pedagogical tool that integrates various academic disciplines and provides a mechanism for contextual learning; and
5. develop an understanding of the relationship between engineering and the liberal arts.

These intended learning outcomes were addressed primarily through a variety of hands-on, cooperative learning activities and related discussions. Directed readings, video, and lectures were used as appropriate. Also, through the Smith Summer Science and Engineering Program, middle and high school teachers were provided with a student teaching opportunity to apply the workshop strategies. Table 1 lists the topics and activities included in the workshop. Details of these workshop elements are provided in the following section.

Topic	Activities
Introduction to engineering and its relationship with the liberal arts	Lecture and discussion
Introduction to design	Discussion, video, group re-design activity
Engineering design process	Group paper airplane design project including prototype construction and presentation
Engineering as a pedagogical tool	Discussion
Elementary engineering content	Engineering materials project
Middle/high school engineering content	Artificial intelligence activity, student teaching experience
Engineering for a sustainable future	Discussion
Group curriculum design project	Student presentations
Engineering and society	Discussion

Table 1 Workshop topics and activities

WORKSHOP CONTENT

Engineering and the Liberal Arts

The workshop curriculum begins with an interactive lecture and discussion on the nature of engineering. Not surprisingly, most students in the workshop were uninformed about what engineers do. A goal of this session was to make them more aware of the nature of the engineering profession—and also to provide a perspective consistent with the philosophy of the Picker Engineering Program. Key to this perspective is an understanding of **the relationship between engineering and the liberal arts**.

The following paragraphs briefly summarize that relationship and offer an overview of the philosophical underpinnings of the Picker Engineering Program at Smith. These paragraphs are excerpts from the opening lecture presented to students on the first day of the workshop.

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It has long been thought that engineering has little to offer individuals seeking a broad liberal education. If information is the currency of democracy, then it can be argued that informed thought and decision-making must be the currency of a sustainable civilization. Indeed, former Harvard President Derek Bok noted that, "Of all our national assets, a trained intelligence and a capacity for innovation and discovery seem destined to be the most important"[4].

But the implementation of new innovations and discoveries must be tempered by the human spirit - an element that is often lacking from the education of engineers. Author Robert Pirsig believed technology should not be "an exploitation of nature, but a fusion of nature and the human spirit into a new kind of creation that transcends both."[5] This is the goal of the Smith engineering program.

At Smith we define engineering as the application of science to serve humanity. This definition necessarily requires that Smith engineers appreciate the human condition, the human spirit. But the engineering program at Smith is not only about our engineering majors. It's about a liberal arts education in the 21st century. Not only do we need more holistically educated engineers, we also need, *desperately need*, a more technically literate public; a citizenry able to participate meaningfully in debates on important issues that face our society – whether they be at the highest levels of government or corporate America or over the backyard fence with neighbors.

There are a variety of modes of reasoning and styles of presentation that prove to be more or less persuasive. Engineering teaches one form of reasoning, one of many. A common misperception is that engineering is another one of the sciences. It is not. Engineering decisions rarely hinge entirely on science. Rather, engineering decisions must consider many other constraints such as economics, safety, accessibility, manufacturability, reliability, and sustainability, to name a few. Engineers must learn to integrate a wide variety of knowledge to make well-informed decisions.

We found that emphasizing the engineering-liberal arts connection at the very beginning of the workshop helped to convince students—who were initially skeptical—that engineering should be included in pre-college education *and* that it should be integrated throughout the various disciplines. When the relationship between engineering and each student's discipline was made explicit, all students were better motivated to benefit from and apply the lessons from the workshop.

Engineering Design

The engineering design process not only is fundamental to the profession, but also offers great potential as an instructional tool in the K-12 classroom. It was our intent to teach the engineering design process and provide our students with positive experiences applying the process. We purposely chose activities that might be appropriate for the students to use later in their own K-12 classrooms. Throughout these activities we emphasized the broad range of potential applications for the design process and therefore its broad applicability for use as a teaching tool. The activities we used to teach design were the following:

1. Students were introduced to the topic through a discussion of the engineering design process as presented in the Massachusetts *Framework* (see Figure 1). It is our belief that the design process is best learned through application, followed by discussion and reflection, so we made this introduction brief.

2. Students worked in teams, applying the engineering design process to redesign aspirin bottles that would allow easier access for physically challenged users. Each group began

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the process by experiencing a simulation of various disabilities: wearing bubblewrap over their eyes, taping fingers together, wearing gloves or using only one arm. After experiencing the frustration of trying to open the bottles under those conditions, the students used the engineering design process to brainstorm ideas for a redesign. In addition to providing experience and increased understanding of the design process, this activity explicitly illustrated how engineering can serve people. At the end of the activity each group shared their ideas with the class. The variety, creativity and ingenuity of the ideas provided a tangible illustration of the effectiveness of the design process. It was also clear that this activity increased student interest in and connection to the engineering field.

3. Students watched and discussed a video illustrating a multidisciplinary team at IDEO redesigning a shopping cart.[6] This video showed a professional design team in action and emphasized the creativity of the design process. It also illustrated the importance of having team members with diverse backgrounds participate in the process.

4. Students designed a paper airplane that is both attractive to children and has a long flight duration. This project was more in-depth than the previous design experiences. It included interviews and consultations with children, consultations with faculty members with relevant technical expertise, the construction of prototypes, and communication of designs through a formal presentation. Several points were made through this project. First, an in-depth understanding of mathematics, science and engineering science can improve the efficiency and effectiveness of the design process. Second, contrary to the conventional view of engineering, good communication and group skills are essential. The students learned through experience the importance of effectively communicating with the product user, communicating their design results, and functioning as a team member. Finally, the high quality and variety of the designs and the high level of student engagement again provided strong evidence of the usefulness of the engineering design process in both business and the classroom.

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1. Identify the need or problem
2. Research the need or problem
    - Examine current state of the issue and current solutions
    - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
    - Brainstorm possible solutions
    - Draw on mathematics and science
    - Articulate the possible solutions in two and three dimensions
    - Refine the possible solutions
4. Select the best possible solution(s)
    - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype
    - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
    - Does it work?
    - Does it meet the original design constraints?
7. Communicate the solution(s)
    - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
    - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
    - Overhaul the solution(s) based on information gathered during the tests and presentation.

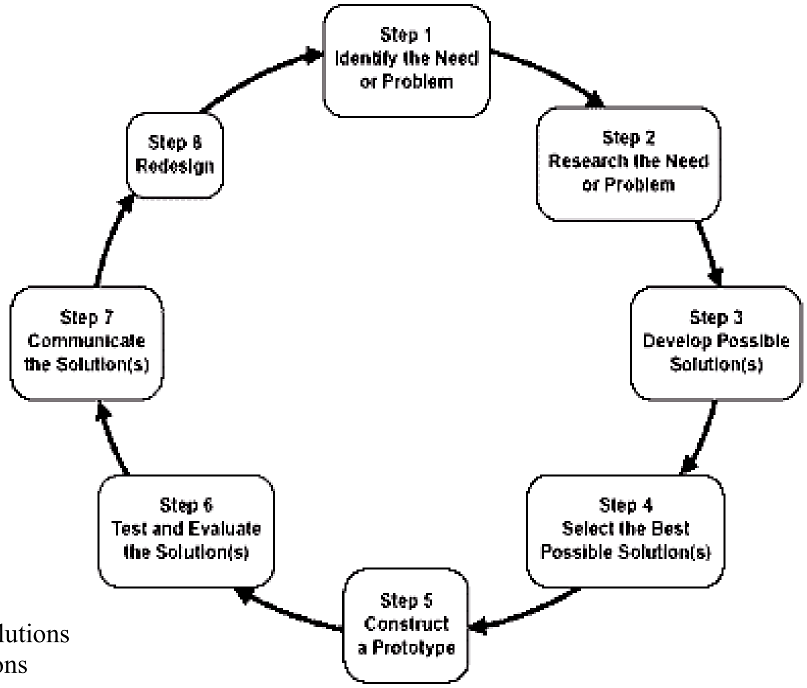

Figure 1 Engineering design process[1]

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Elementary School Activities

The goal of the elementary school activities section of our workshop was to engage the student teachers in lessons and experiences that reflected the learning standards for engineering education, pre-kindergarten through grade five, as articulated in the *Massachusetts Science and Technology/Engineering Curriculum Framework*. The pre-K through elementary scope and sequence in the engineering curriculum focuses on the materials and tools of engineering and the engineering design process. More specifically, the learning standards in the *Framework* for engineering in grades PreK-2 and grades 3-5 are the following (taken directly from the *Massachusetts Science and Technology/Engineering Curriculum Framework, 2001, pages 54-55)*:

I. Grades PreK-2
1. Materials and Tools
Broad Concept: Materials both natural and human-made have specific characteristics that determine how they will be used.

2. Engineering Design
Broad Concept: Engineering design requires creative thinking and consideration of a variety of ideas to solve practical problems.

Grades 3-5
1. Materials and Tools
Broad Concept: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

2. Engineering Design
Broad Concept: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.

Each of these standards is further broken down into discrete intended learning outcomes in the *Framework*. We developed and implemented three activities to illustrate to the student teachers how these learning standards could be addressed in the preK-elementary classroom curriculum: Activity I: Getting Dressed in the Morning; Activity II: Touch and Discover; and Activity III: Compare Fabric Materials. These learning experiences are presented and discussed in detail in Appendices I – III. We include a summary of each experience here:

Activity I: Getting Dressed in the Morning. This activity related the familiar, everyday task and routine of getting dressed each day to the engineering design process: Identify the need or problem; research the need or problem; develop possible solutions; construct a prototype; test and evaluate the solution(s); communicate the solution(s); and redesign.

Students brainstormed other everyday scenarios that call for the application of the engineering design process. The goal was to move students to encounter a more traditional engineering design problem, although making an authentic connection to the students' real-world knowledge continued to be an important instructional consideration.

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Activity II: Touch and Discover. Students worked in pairs or small groups to identify and categorize various materials. One student in each group was blindfolded. S/he chose five different materials to identify. Solely through touch, the blindfolded student had to describe and try to identify the material. The other student(s) in the group recorded the observations of the blindfolded student, who then attempted to describe the material by its characteristics/properties and speculate as to its possible uses. (This activity can be modified to challenge different age or ability groups. Common modifications include using a variety of natural materials or including a more thorough investigation of the selected materials by weighing them, scratching them, checking for conductivity, etc.)

The Touch and Discover activity helps students practice observation and tactile perception skills; teaches sorting and categorizing, using qualities and attributes; increases technical and scientific vocabulary; and reinforces descriptive language and communication and writing skills.

Activity III: Compare Fabric Materials. Students examined different types of fabric and their respective individual properties. Using magnifying glasses and sandpaper, they tested the weave of fabrics and the wear quality to sample fabrics. Through the comparison of the qualities of different fabrics, students better understood why there are so many different types of fabric. They also recognized and/or suggested different uses for each fabric.

The Compare Fabric Materials activity teaches students about the structure of a material (in this case, fabric/textiles). It also engages the students in basic experimental testing and teaches them how to use a magnifying glass to observe closely.

After the students in the workshop successfully completed the three activities, they brainstormed ways that each of these experiences (and their accompanying engineering learning standards) could be applied to different content areas of the elementary school curriculum: the language arts, science, mathematics, social studies, the visual and performing arts, and physical education. Students clearly saw the power and potential for extended, interdisciplinary connections and learning inherent in each of the activities. Examples of some of their ideas are as follows:

- for building descriptive language and communication skills (the language arts);
- for teaching and learning about inventing, experimenting, and problem solving (science);
- for teaching and learning about data gathering, organization, representation, interpretation, and analysis (mathematics);
- for understanding ecological, environmental issues and stewardship (social studies);
- for practicing three-dimensional visualization and design (the visual arts);
- for simulating design and redesign-based processes and projects (the performing arts); and,
- for viewing and appreciating the human body as a kinesthetic instrument and well-engineered system (physical education).

High School and Middle School Activities

Developing expertise in engineering content areas was beyond the scope and intention of the workshop. Instead, in the first activity, we focused on one topic that illustrated how technology/engineering can be used to integrate subject areas and engage students. The topic that we chose was the Turing test. This test can be described as follows: Imagine that you are a

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judge sitting at a computer terminal that is connected at the other end to either a person or a computer. If no amount of questioning or conversation allows you to tell which it is, then the machine has passed the test. Students in the workshop learned about the Turing test and participated in a number of activities that utilized the ideas behind it. These activities are described and discussed in detail in Ellis and Andam[7] and summarized here:

- Students generate questions to be used in the test and discuss their potential effectiveness. For example, a question requiring real-world knowledge or an understanding of semantics will be more effective.
- Students play a version of the game described by Turing[8] in which a male and a female replace the person and computer. Both try to convince the judge that they are female and the judge must try to identify the imposter.
- Students converse with chatterbots—programs that imitate human conversation—and try to identify their logic structure and rate their effectiveness for imitating humans.

After the students worked through these activities, they devised a lesson plan and used the same activities to teach a class of middle school girls attending a summer program at Smith College. The education students started the class with a discussion on machine consciousness. This introduced the girls to artificial intelligence, a field that was unfamiliar to most of them. After the discussion, the education students led the girls through the gender identification version of the Turing game described above. The girls were engaged in this section of the class because they discussed familiar topics like fashion and how males and females view it differently. This also offered an opportunity for the education students to engage the students in a discussion about gender and stereotypes. To end the class, the girls applied what they had learned by conversing with several chatterbots through the Internet. The interactive nature of this activity was also popular with the girls.

Although the field of artificial intelligence and the idea of teaching a class in the subject initially intimidated the education students, they quickly became knowledgeable in the subject and their student teaching experience was a very successful one. Most encouraging in this teaching experience was that each of their different content backgrounds prepared them to teach the class. For example, the pre-service English teacher led a discussion about the importance of semantics in understanding language and the mathematics teacher used the activities to present topics in logic. So through this student teaching experience, the workshop teacher actually experienced the potential of engineering as an instructional tool.

In the second activity, students investigated engineering for a sustainable future. First they calculated the size of their ecological footprint (the land area required to sustain their lifestyle). Later they examined the life cycle of a shoe and attempted a re-design to lower its environmental impact. Because many of the students were interested in environmental issues, they were encouraged that engineering could be used as an instructional tool in this area.

In the final activity, the students were divided into two interdisciplinary teams. Each team was asked to develop an interdisciplinary curriculum unit that utilized engineering design and involved all of the group members' subject areas. One group was particularly creative and

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developed a plan for a unit based on an idea presented earlier in the workshop: how technology causes isolation in society.

This group planned a unit in which students would first investigate "man's isolation in post-modern society" in each of their disciplines. For example, students would read Don DeLillo's *White Noise*[9] in English class. There is a scene in the book where people admire a beautiful sunset caused by pollution. In physics class, students would discuss how pollution creates such sunsets. In biology class, they would discuss the environmental issues raised in the book and means to solve them. In mathematics class, students would analyze data about pollution in the environment. After the students investigated the topic, they would use the engineering design process to solve the problem of man's isolation in post-modern society. The students would finish the unit by sending a letter to a politician that included sufficient evidence and their suggested solutions. The group noted that the letter could be sent via email and thus their students would use technology to solve the isolation created by technology.

ASSESSMENT

Students completed pre- and post-workshop attitude surveys that assessed their views on the general quality of the workshop, the effectiveness of the workshop in meeting the intended learning outcomes, their perception of the field of engineering, and their future plans for using engineering in their K-12 classrooms. All of these instruments indicated that the workshop was successful. For example, 95% rated the experience good or excellent, 100% would recommend the workshop to others, and 95% found the workshop useful or very useful. Numerous students wrote additional comments that often indicated a fear of or antipathy for engineering upon entering the workshop. They explained how much their attitudes and beliefs had changed as a result of their participation in the workshop. The following are typical responses.

> This was excellent! I'm definitely an artsy, language arts, and performance type person and so I badly needed to expand my thinking into this area--this has taken a lot of the FEAR out of it for me!
>
> I really learned a lot about engineering. It was wonderful! I have so many ideas for how to include it into the classroom. Now I know how important it is to get great people into the profession as well.
>
> I dreaded coming here and am shocked at how much I learned. I enjoyed this experience very much!
>
> This was excellent--I am no longer afraid of engineering--I think it was very useful to show us the frameworks.
>
> I never thought that I could be interested in Engineering! Go figure!

Table 2 shows student beliefs regarding the effectiveness of the workshop for meeting the intended learning outcomes and whether they intend to use engineering in their classrooms. The first five statements in Table 2 show student beliefs regarding the effectiveness of the workshop

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for meeting the intended learning outcomes. This table shows that most students entering the workshop did not feel knowledgeable about the engineering field, the state technology/engineering framework, the engineering design process, the potential use of engineering as an instructional tool, or the relationship between engineering and the liberal arts. At the conclusion of the workshop, a majority of students indicated that each of the intended learning outcomes was met.

The final statement in Table 2 assesses the students' intentions to make engineering a part of their future teaching. Again, the results were promising as the number of students intending to use engineering rose from 24% to 84%. In the post-workshop survey, all students were asked to give examples of how they would use engineering in their future teaching. The following are two example responses from pre-service elementary teachers.

> I hope to use engineering to help solve problems in the classroom, especially those involving logistical or design elements. I will relate the collaborative process involved in design to the collaborative process involved in democracy.
>
> 1. The process that engineers use would be a great process to use in solving some of the problems we encounter as a class. For instance, how can we best provide the kids with water after recess--disposable cups? Water bottles, plastic cups, etc. . . . 2. I'd love for the kids to work in groups building and/or designing something--a bridge, a tower, paper airplane, egg vehicle. 3. Categorizing different materials and looking at their properties.

Statement	Participants Who Agree or Strongly Agree	
	Pre-Workshop	Post-Workshop
I am familiar with the field of engineering.	12%	72%
I am familiar with the *Massachusetts Science and Technology/Engineering Curriculum Framework*.	12%	78%
I have a basic understanding of the engineering design process.	18%	83%
I have a basic understanding of engineering as a pedagogical tool that integrates various academic disciplines and provides a mechanism for contextural learning.	12%	94%
I have a basic understanding of the relationship between engineering and the liberal arts.	12%	89%
I intend to include engineering as part of my future teaching.	24%	84%

Table 2 Comparison of pre- and post-workshop student survey responses.

Students were also asked to write what the term "engineering" meant to them both pre-workshop and post-workshop. Five typical responses are shown in Table 3. These student responses indicate a more focused, sophisticated and accurate view of engineering after the workshop. They also indicate a marked change in student awareness of the non-technical dimension of engineering. For example, in the pre-workshop survey few students mentioned that engineering

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serves humanity and meets society's needs, but the opposite was true in the post-workshop survey.

Pre-Course Response	Post-Course Response
Engineering is a field in which people design physical structures and organizational systems. It combines the physical sciences with the practical needs of society.	Engineering is a wide-ranging field in which people use science and technology to help improve our quality of life. Engineering has been viewed as a field in which problems are solved. This is true, but there is more. Engineering helps shape society and reflects society's values.
When I think of engineering I tend to think of mechanics and "how things work." I suppose that, more abstractly, engineering deals with logical reasoning and planning. My uncle is a plastics engineer and I've always felt as if we speak a different language!	My answer is not entirely different now than it was before the program--engineers are problem solvers. The main difference is that before I always thought of the math and science portion of engineering but never about the "to help/serve humanity." I had also not thought of the importance of engineers when approaching our environmental problems, which is an issue that is important to me.
Engineering is using technology to make things work. It's designing things. For instance--recently there was an article in the paper about a new kind of wheelchair that--well, it's not really a chair it allows the person to stand and move in an upright position. Took lots of engineering to get that to work safely!	Engineering is the application of science and technology to serve humanity. Engineering affects everything from the bridge you drive over, to the toothbrush you brush your teeth with, to the food on the supermarket shelves. Engineers take on a problem and try to solve it in the most efficient way.
No response	The application of science, technology, and problem-solving to problems which affect people/humanity, with an eye to the interest and benefit of people/humanity.
No response	Using science and math as tools to help humanity with specific approach to problem-solving, i.e. the engineering design cycle. Uses a lot of math and science--but its intent should be serving humanity. If "humanity" component is lost, engineering can be dangerous--can destroy environment, etc.

Table 3 Sample student responses to the question, "What does the term 'engineering' mean to you?"

DISCUSSION AND CONCLUSION

The results and assessment data convince us that the pre-service teachers completed the week's engineering workshop ready to explore engineering design principles and content at all grade levels and in all subject areas. These are promising and satisfying results. In reviewing the assessment data and the workshop curriculum, we believe that there are three fundamental reasons for the workshop's success:

1. Building on students' previous knowledge and experiences: Students were asked to define their conceptions of engineers and the field of engineering at the outset of the workshop. The first lectures and discussions of the week focused on the socially responsible/serving humanity goal of engineering as it is taught at Smith College, illustrated engineering's relationship to the liberal arts, and provided students with examples from the real world practice of today's engineers. We believe that this captured

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the interest and imagination of the students from the start of the workshop. It challenged their preconceived notions of the traditional conception of the engineer and opened them up to considering and exploring the field of engineering in new, innovative, and less intimidating ways. All students (from all disciplines) could easily and comfortably relate to the socially responsible mission and liberal arts focus of engineering education. They then became intrigued and poised to learn more.

2. The teaching team of the workshop was truly interdisciplinary and represented the K-12 -College continuum: One faculty member was from the Picker Engineering Program at Smith, another was a professor of education and child study (with a specialty in elementary education), and the third faculty member was a secondary school technology teacher and chair of his public school's engineering/technology program (preK-12). The faculty team provided a model for the students of interdisciplinary collaboration and inquiry at its best. The workshop design was created and implemented by the faculty team, and planning and teaching roles were equally shared. Students in the workshop were able to benefit from seeing faculty work together in ways not traditionally experienced in academic settings, especially at the college/university level. Each faculty member interpreted and discussed the curriculum content of the workshop through his or her own disciplinary filter; therefore, students were able to consider a multiplicity of perspectives and understandings as presented by the faculty team. We believe that this set a climate of intellectual openness and honesty during the workshop sessions; modeled risk-taking and interdisciplinary thinking and doing; and invited students to move beyond their own academic comfort zones and supported them in their explorations.

3. The engineering education workshop was required for all the graduate students pursuing the EdM and MAT degrees at Smith. The workshop was a part of their first semester in the graduate program. The required nature of the workshop and its placement during the beginning stages of their graduate program implicitly reflected its academic and professional importance in their course of study. Experiencing the engineering design process and learning about its relationship to thinking and learning in the liberal arts provided the students with a conceptual framework, which they can apply to their own curriculum planning and instruction in their student teaching classrooms in the semesters to follow. Their new knowledge and enthusiasm about engineering and how to integrate it creatively and meaningfully into K-12 education now needs to be nurtured and supported throughout their student teaching practica. Student teachers' habits of mind and practice in engineering education can only be further developed, strengthened, and sustained through their consistent and regular application of the methods and materials of engineering in their classrooms, with their students. The challenge now for the faculty team, therefore, is to follow these students' progress as student teachers, encouraging and supporting them in their efforts to apply what they learned in the engineering education workshop to their own teaching, thereby advancing the technical literacy of our nation.

> "A person that understands—with increasing sophistication—what technology is, how it is created, how it shapes society and in turn is shaped by society, is technologically literate."[10]

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APPENDIX I
Using the Engineering Design Process to Get Dressed in the Morning

1 *The problem* is that you need to get dressed for school or work this morning so that you look good and are protected from the elements.

2 In *researching the problem* you need to find out what the weather is going to be today, which of your clothes are clean and what you might do after school or work.

3 In *developing possible solutions* you might look at possible combinations of clothing, footwear and protective clothing.

4 You will need to make a decision and *select the best of the solution*s available.

5 In the "everyday task" scenario we deviate a bit from the sequence, since this is a situation in which we would simply get dressed rather than *construct a prototype*. In the traditional engineering design process, you would build a prototype or model.

6 The next step of the design process is to *test the solution* and verify whether the problem is solved. When you stand in front of the mirror and look at the clothing combination, you are evaluating the solution. When your parent or spouse tells you that the combination does not work, you have another evaluation. When you walk outside to find the weather colder than you anticipated and return for a heavier coat, that's yet another evaluation of your solution. In the traditional engineering design process, you would draw on mathematics and science and use more formal methods like simulations and modeling to test solutions.

7 The *communication step* is self-discovery or feedback from others. In the traditional engineering design process, you would communicate via discussions among the design team, funding agencies, and regulatory agencies.

8 In the *redesign* process, the information from testing and feedback communicated in the previous steps is used to revise the solution and make it better. In our example, you might go back to get a coat or change your shirt to better match your pants.

Note:
Other everyday scenarios you could use are: "What do I do about lunch today?" and "What are we going to do for fun on Friday night?"

A more traditional engineering design problem works best if the problem you identify is something that the students can relate to. Local papers are full of articles relating to proposed schools, public safety complexes, bridges, roads, and sewage and water facilities. Using mathematics, science and modeling, students can work through the engineering design process to solve any of these problems.

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APPENDIX II
Touch and Discover Activity
(Based upon *Touch and Discover*[11])

Grade Levels: PK-2

Summary:
Students work in pairs or small groups to identify and categorize various materials. One student is blindfolded and chooses five different materials to identify. The blindfolded student may use only touch to describe and identify the material and its possible uses. The other students in the group then record the observations of the blindfolded student. The activity can be modified so it is more challenging for different age or ability groups. Common modifications include using a wide variety of natural materials or conducting a more thorough investigation of the selected materials by weighing, scratching, checking for conductivity, etc. Students can also brainstorm uses for the materials.

Level of Difficulty: (1=least difficult: 5=most difficult) 3- marginally difficult

Time Required: 45-60 minutes

Cost: Variable, depends on access to a variety of materials. Preparation time might be significant the first time you gather materials.

Massachusetts Science and Technology/Engineering Standards met:
Students should be able to:
1.1 Identify and describe characteristics of natural materials (e.g. wood, rocks, wool) and human-made materials (e.g. Styrofoam, plastic, fabric).
1.2 Identify and explain some possible uses and advantages for natural and human-made materials.

What Will Students Learn?
The students will:
- Build observation skills by using tactile perception to describe and distinguish objects.
- Learn how to categorize and sort objects/materials in a logical fashion.
- Increase technical/scientific vocabulary.
- Reinforce language skills and writing skills.

Background Information:
It's helpful to provide some prior discussion of how materials might be grouped and the differences among human-made, natural, living and non-living materials.

Materials:
- Blindfolds or small containers (enough for half the class)
- Boxes or bags to hold the materials
- Paper and pencils to log the characteristics and the guess

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Suggestions:

- Ensure that there is a large enough selection of objects so the children will have their own objects and each partner will identify different objects. Objects should include human-made and natural materials of different weights, textures and hardness.

- Materials might include: similarly sized pieces of rock, concrete, brick, hardwood, softwood, sponge, clay, rubber hose or tubing, solid and hollow pieces of metal, solid and hollow pieces of different types of plastic.

Preparation:

The following items should be ready for the activity:

- Bags or boxes for each group filled with the different materials/objects the teacher has been able to find.
- Blindfolds/paper bags or small boxes (whichever the teacher wishes to use).
- Lab sheets for logging observations and possible uses.

Directions:

Discuss with the children ahead of time different methods of grouping materials/objects (weight, hardness, texture, strength). Discuss the differences between natural and human-made materials, and living and non-living materials.

Have the students break into groups (two is the best), and get the blindfolds.

1. Blindfold partner A. Partner B picks up one of the bags of materials/objects.
2. Partner A reaches into the bag and selects one of the material samples.
3. Partner A holds the material sample and thoroughly examines it by touch and describes the object to the partner.
4. Partner B records the observations/data on the worksheet provided
5. After partner A has selected and described five materials the bag is returned to the table.
6. The activity continues with the children reversing roles and repeating steps one through five above.
7. Once both partners have had an opportunity to identify materials/objects, explore how the ten materials/objects that were selected might be grouped. Think of how they are related to each other and their different uses. Explore how the activity would change if the students were not blindfolded.

You could ask the children to expand on this activity by bringing in a number of materials/objects from home. These materials/objects should be grouped according to characteristics they share. (Note: Make sure that the children do not bring in any materials that are sharp or dangerous in other ways.)

Extensions:

- Have students describe the material/object to the class.
- This can help students in developing their language and descriptive skills, and can also assist all students with listening and visualization skills.

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- Matching games can be developed in a variety of ways, such as matching a material they can only feel with those they can see, or matching a material by category, use or its origin.

Discussion:
How did each group categorize the different materials/objects?
Is there only one right way to group materials/objects?
Which ways are better? What are the best characteristics to use when grouping materials/objects?
How easy/hard was it to identify and describe materials/objects using only touch? Why?
Why is it good to practice using different observation skills?

Notes:
The more experienced the children are, the more challenging you can make the activity. The children can pick out five similar materials/objects for their partners to identify, or pick out five materials/objects that they grouped in a certain way and have the partner try to identify the grouping method.

Investigating Questions:
How can different materials/objects be categorized by using only the sense of touch?
Why is it important to be able to categorize different materials/objects?
How do engineers use information like this to help them?

Sample Worksheet:
As the children develop their skills, they should use more descriptive words and more sophisticated methods of sorting. Beginners should be expected to sort according to weight and texture while more advanced students will be able to sort by degrees of hardness or flexibility and even potential uses. There should be a mix of simple, easy to distinguish materials along with some more difficult materials of similar characteristics. The basic idea is to have students identify basic characteristics of materials and group them by those characteristics. Projecting those characteristics to potential uses can be a challenging and fun activity for children in this age group.

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APPENDIX III
Comparing Fabric Materials
(Adapted with permission from *The Best of Wonderscience*[12])

Grade Levels: 3-5

Summary: Students will look at different types of fabric and their respective individual properties. Using a magnifying glass and sandpaper, they will test the weave of fabrics and the wear quality of sample fabrics. By comparing the qualities of different fabrics, they will better understand why there are so many different types of fabric and be able to recognize or suggest different uses for them.

Level of Difficulty: (1=least difficult: 5=most difficult) 4-difficult

Time Required: 30-45 minutes

Cost: $5 - $15 or less depending on availability of materials at school

Massachusetts Science and Technology/Engineering Standards:

- 1.1 Identify materials used to accomplish a design task based on a specific property, e.g. weight, strength, hardness and flexibility.
- 1.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers and lists.

What will the students learn?

1. How to use a magnifying glass
2. The structure of fabric
3. Basic experimental testing skills

Background Information:
Vocabulary for the activity:

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BREAKTHROUGH: a sudden advance in knowledge or technique; point when a hole is created through a barrier
FABRIC: a woven or knitted material/cloth
FIBER: a slender and long natural or synthetic unit of material (like wool, cotton, asbestos, gold, glass or rayon) usually able to be spun into yarn
MAGNIFYING GLASS: a lens that magnifies objects viewed through it
SANDPAPER: paper with rough material (like sand) fixed on one side and used for smoothing and polishing
THREAD: a thin fine cord formed by spinning and twisting short fibers into a continuous strand
WEAR: damage, destruction, or marks of use by scraping or rubbing
WEAR and TEAR: the loss or damage that occurs to something in the course of normal use
WEAVE: any pattern or method of weaving; to make on a loom by lacing together threads going lengthwise with threads going crosswise

Resources:
www.hollandandsherry.com/textileguide/fabrics.html - good descriptions of different types of fabric
www.utexas.edu/depts/bbr/natfiber - provides links to sites dealing with natural fibers
www.wholeearthmag.com/ArticleBin/113.html - gives descriptions of different synthetic fibers
www.fpsmith.com/weaves1.htm - describes different types of weaves

MATERIALS: (per group)
- magnifying glass
- three different pieces of fabric (i.e., nylon stocking, lightweight cotton, denim)
- baseball or heavy ball
- extra course sandpaper
- rubber band

Preparation:
- Obtain materials.
- Cut each fabric into 4 ¼-inch by 11-inch pieces.
- Photocopy the "Fabric Wear and Tea" chart (see link).

Directions:
Part One: Observation
1. Put students in groups of two.
2. Give each group one piece of each type of fabric.
3. Have the students use a magnifying glass to look closely at each fabric.
4. Instruct each group to draw what each fabric weave looks like on a data sheet.

Part Two: Fabric Wear and Teat
1. Give each group a baseball or heavy ball.
2. Have each group wrap one of their pieces of fabric tightly around the ball and secure with a rubber band. (Note: The tighter the fabric is, the faster the experiment progresses).

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3. Within each group, one partner should secure a piece of sandpaper (rough side up), while the other partner drags the ball across it. DO NOT press down on the ball; let the weight of the ball drag once across the sandpaper.
4. The students should use the magnifying glass to observe the area where the fabric was dragged across the sandpaper. Question for discussion: Was there any wear after just one scrape?
5. Students should continue to test the fabric one scrape at a time. After each successive scrape, they should examine the area with the magnifying glass, counting each scrape until they notice some wear on the fabric. Students can make a tick mark on the data sheet for each scrape.
6. When students notice some wear on the fabric, have them count and record the number of scrapes in the chart under "First Wear" for the tested fabric.
7. Have the students continue scraping the fabric and counting each scrape until they notice a hole or tear.
8. Record the number of scrapes in the chart under "Breakthrough" for that fabric.
9. Repeat steps 2 to 8 for each of the other two fabrics.

Investigating Questions:
1. What makes fabrics different?
2. Which fabrics are the strongest?
3. Why do certain part of your clothes, such as the knees of pants or the elbows of shirts, wear faster than other parts?
4. Which fabrics needed the least and most scrapes to show the first signs of wear?
5. Which fabric lasted the longest between the first signs of wear and the breakthrough point?
6. Which fabric qualities do you think were the most important for the durability of the fabric (e.g., type of fiber in the thread, strength of the thread, type or tightness of the weave)?

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