Engineering the Future: A Workshop for High School Teachers

Suzette R. Burckhard[1], Judy Vondruska[2], Kenneth Emo[4], Stephen Gent[3], Erin Cortus[5], Christopher Hay[5], Zach Gutzmer[6]
[1]Professor and [6]Instructor, Civil and Environmental Engineering Department, [2]Instructor, Physics Department, [3]Assistant Professor, Mechanical Engineering Department, [5]Assistant Professor, Agricultural and Biosystems Engineering Department, South Dakota State University, Brookings, SD
[4]Assistant Professor, Division of Education, University of Minnesota-Morris, Morris, MN
(e-mail: Suzette.Burckhard@sdstate.edu)

Abstract

The framework guiding the development of Next Generation Science Standards (NGSS) identifies eight science and engineering principles essential for all students to learn. The Engineering the Future workshop, offered by South Dakota State University (SDSU) in the summer of 2012, focused on helping teachers better understand those principles and how to employ them effectively in their classrooms. Each day of the week-long workshop, teachers participated in a variety of engineering-related activities, accessed low and high-end instrumentation, took tours of engineering-related facilities in the region, and developed lesson plans to incorporate what they learned into their science classrooms. We used pre- and post-workshop surveys to assess the participants' understanding and attitudes regarding science and engineering. Results of the survey showed participants had a narrow view of engineering prior to the workshop but by the end of the workshop, they were more aware of the nature of engineering, the various types of engineering, and they better understood how they could incorporate engineering principles into their current curriculum.

Key words: Outreach, Next Generation Science Standards

Background

Many students are unable to make connections between what they are learning and how they are to use that knowledge in related classes or outside the classroom. By using a contextual learning environment, students can discover meaningful relationships between abstract ideas and practical applications. Contextual learning is a proven concept that incorporates much of the recent research in cognitive science[1]. By using a contextual learning environment, students can discover meaningful relationships between abstract ideas and practical applications. One context that is only recently being introduced into K-12 learning environments is engineering. The barrier to successful implementation of engineering for contextual learning is the lack of understanding of the field by teachers and students alike.

According to a study performed by the National Academy of Sciences, the general public has little recognition of the contributions of engineers as the source of the technology that makes our modern life possible[2]. Another survey on the public perception of engineering shows that the public does not understand what engineers do. When various individuals were asked what an engineer does, their responses included, Locomotive Train Operator, Mechanic/Technician, Construction Managers, NASA Flight Controllers, Computer "persons," and "Dot-Commers." In general, engineers were associated with being simple builders, operators, or maintainers of the world around us, not the designers, creators, and inventors that they are[3]. In South Dakota, 2.24% of the workforce is considered to be in a science or engineering occupation out of 408,805 working individuals. Engineers work in every county within South Dakota, as well as many of the larger cities. The number of engineers employed in South Dakota was 1,850 or 0.45% of the state workforce. This percentage is lower than most other states but similar to surrounding states, except Minnesota with 1.06% of the workforce being engineers. It was noted that states with higher concentrations of engineers employed also have relatively high concentrations of high-technology businesses[4]. With the low percentage of engineers in the state, it is perhaps not surprising that students and teachers have misperceptions about the nature of the profession.

Engineers are creative individuals who work on complex problems by employing skills in mathematics and science, although this is not the impression most people have of engineers. Engineers are the creative hand behind technology development and are intimately involved in bringing science discoveries into general usage, such as televisions, microwave ovens, GPS, medical devices and cellular phones. Without the involvement of engineers, these products would have remained in use by a small percentage of the population and not by the general public.

The International Technology Education Association (ITEA) commissioned a survey of the American public to assess their views on technology, which is closely linked to engineering study, research, and practice. In the ITEA/Gallop Poll survey, the American public was virtually unanimous in regarding the development of technology literacy as an important goal. Technology development was perceived to generate economic growth and a more comfortable lifestyle. There was nearly total consensus that schools should include the study of technology in their curriculum. At the same time, the American public identified technology as being related to computers and the Internet, not a broader view of other pervasive technology we use every day[5].

The idea that engineers work exclusively on computers is also quite prevalent. Stereotypical representations of engineers show them as white, male, geeky or nerdy individuals with poor social skills who work on computers while surrounded by piles of paper and empty food containers. Engineering should be an attractive and popular field of study for bright and creative students of both genders and all races. By introducing engineering into K-12 school curriculums and involving practicing engineers in the teaching process, the inaccurate view of what engineers do and are can be changed, thereby attracting a more diverse group into the study of engineering[3].

Gomez [6] conducted a comparison study of 250 junior high school students studying engineering, art, and physics curriculums. He assigned each student a task of solving a problem involving the design of a paper hanger to support a 500 gram weight. He gave students three iterations to produce the hanger. The engineering students completed the task more consistently when compared to either art or physics students. The engineering students used calculations as they worked from one design to the next. After three iterations, they were able to construct the lightest hangers followed by the art and then the physics students. Although each group was able to produce a prototype hanger according to the problem constraints, the engineering students worked more quickly and made greater design changes at each iterative step. By using engineering concepts as the context for teaching science and mathematics in the school curriculum, the students developed better critical thinking skills and solved the open-ended problem more efficiently. The goal of developing better critical thinking skills by teaching engineering fits the National Science Foundation's recommendations on teaching the process of the engineering discipline as the context for teaching and learning math and science[6] and is reflected in the Framework guiding the development of the new Next Generation Science Standards (NGSS). standards[7]. The Framework for the NGSS outlines eight distinguishing practices in science and engineering as shown in Table 1.

Table 1: Summary of Eight Distinguishing Science and Engineering Principles from NGSS 2011

SCIENCE	ENGINEERING
Practice 1 - Asking Questions and Defining Problems	
...[B]egins with a question about a phenomenon.... A basic practice of the scientist is formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered.	...[B]egins with a problem, need or desire that suggests an engineering problem that needs to be resolved.... Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.
Practice 2 - Developing and Using Models	
...[O]ften involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomenon. Models make it plausible to go beyond observables and imagine a world not yet seen.	...[M]akes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem. Engineers also call on models of various sorts to test proposed systems and to recognize the strengths and limitations of their designs.
Practice 3 - Planning and Carrying Out Investigations	
...[M]ay be conducted in the field or the laboratory. A major practice of scientists is planning and carrying out a systematic investigation, which requires the identification of what is to be recorded and, if applicable, what are to be treated as the dependent and independent variables.	...[U]se investigations both to gain data essential for specifying design criteria or parameters and to test their designs. ...[M]ust identify relevant variables; decide how they will be measured, and collect data for analysis. Their investigations help them identify how effective, efficient, and durable their designs may be under a range of conditions.

SCIENCE	ENGINEERING
Practice 4 - Analyzing and Interpreting Data	
...–[P]roduce data that must be analyzed in order to derive meaning. ....scientists use a range of tools - including tabulation, graphical interpretation, visualization, and statistical analysis - to identify the significant feature and patterns in the data. Sources of error are identified and the degree of certainty calculated.	...[A]nalyze data collected in the tests of their designs and investigations; this allows them to compare different solutions and determine how well each one meets specific design criteria.... Like scientists, engineers require a range of tools to identify the major patters and interpret the results.
Practice 5 - Using Mathematical and Computational Thinking	
...[M]athematics and computation are fundamental tools for representing physical variables and their relationships.... Mathematical and computational approaches enable predictions of the behavior of physical systems, along with the testing of such predictions... statistical techniques are invaluable for assessing the significance of patterns or correlation.	...[M]athematical and computational representations of established relationships and principles are an integral part of design.... Moreover, simulations and designs provide an effective test bed for the development of designs and their improvement.
Practice 6 - Constructing Explanations and Designing Solutions	
The goal of science is the construction of theories that can provide explanatory accounts of features of the world.... Scientific explanations are explicit applications of theory with the intermediary of a theory-based model for the system under study.	Engineering design, a systematic process for solving engineering problems, is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, esthetics, and compliances with legal requirements.
Practice 7 - Engaging in Argument from Evidence	
... [R]easoning and argument are essential for identifying the strengths and weaknesses of a line of reasoning and for finding the best explanation for a natural phenomenon. Scientists must defend their explanations, formulate evidence based on a solid foundation in light of the evidence and comments offered by others, and collaborate with peers in searching for the	...[R]easoning and argument are essential for finding the best possible solution to a problem. Engineers collaborate with their peers throughout the design process, with a critical state being the selection of the most promising solution among a field of competing ideas. Engineers use systematic methods to compare alternative, formulate evidence based on test data, make

SCIENCE	ENGINEERING
best explanation for the phenomena being investigated.	arguments from evidence to defend their conclusions, evaluate critically the ideas of others, and revise their designs in order to achieve the best solution to the problem at hand.
Practice 8 - Obtaining, Evaluating, and Communicating Information	
... A major practice of science is... the communication of ideas and the results of inquiry - orally, in writing, with the use of tables, diagrams, graphs, and equations, and by engaging in extended discussions with scientific peers. Science requires the ability to derive meaning from scientific texts (such as papers, the Internet, symposia, and lectures) to evaluate the scientific validity of the information thus acquired, and to integrate that information.	...Engineers need to be able to express their ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussion with peers... as with scientists, they need to be able to derive meaning from colleagues' texts, evaluate the information, and apply it usefully.

Most teachers have not had any exposure to engineering or engineering practices during their teacher training in college. Accommodating this new expectation with the NGSS will be challenging without additional training such as the Engineering the Future workshop.

We designed the Engineering the Future (ETF) workshop with the goals of assisting teachers in

- understanding the day-to-day activities of an engineer and the similarities and differences between science and engineering;
- understanding that engineering is more than electrical, mechanical and civil; in particular, exposing them to such fields as environmental engineering and agricultural engineering;
- developing or modifying curriculum to meet the new NGSS engineering principles requirements and connecting engineering activities with science standards; and
- identifying and developing relationships with engineers in practice within their own community and the region.

Workshop Overview

Since science teachers have little time to add additional content into their curriculum, we designed this workshop to assist teachers in connecting engineering principles with science standards, so that both can be addressed at the same time. We focused on helping teachers clearly recognize their current uses of engineering ideas in their science classes but also helped them incorporate additional principles into their existing curriculum. Each day of the week-long workshop consisted of informational sessions about various engineering disciplines, hands-on activities, tours, and curriculum work, linking engineering activities with science standards. A wiki site (http://etfworkshop.wikispaces.com/) was set up to facilitate collaboration both during the workshop and afterwards. Table 2 presents an example of the week's activities.

Table 2 - Initial Schedule Overview for Engineering the Future Workshop

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Registration Introductions - *Suzette Burckhard, Judy Vondruska* Welcome -Dean of Engineering	Agricultural and Biosystems Engineering and Environmental Engineering - *Chris Hay, Erin L. Cortus*	Presentations Lessons Plans incorporating Agricultural and Biosystems Enginering	Presentations of Lesson Plans incorporating Mechanical Engineering	Presentation of Lesson Plans incorporating Structural Engineering
Pre-Workshop Survey of Participants: Ken Emo	Overview of Agricultural and Biosystems Engineering and Environmental Engineering	Overview of Mechanical Engineering - *Stephen Gent*	Overview of Structural Engineering - *Suzette Burckhard, Zach Gutzmer*	Overview of Electrical, Computer, and Software Engineering - *Madeleine Andrawis*
Hands-on activity - Scavenger Hunt: Engineering All Around Us	Hands-on activity - Surface runoff with Rainfall simulator trailer versus modeling results,	Hands-On activity - Bicycle Mechanisms	Hands-on activity - structural design simulation, Lab tours - Civil Engineering	Hands-on activity - Digital computers and counting
Presentation on Engineering Philosophy and Linkages to Science and Math Standards	Hands-on: Classroom activity - Sizing a manure lagoon	Hands- on activities - Thermal/Fluids systems: w/pancakes, energy usage audit, energy analysis	Hands-on activity - Stress and Strain, Testing Structures	Hands-on activity - Parallel and Series Circuits
Group discussion - What do you do now; how does it relate to engineering?	Wastewater treatment Plant tour		Hands-on activity - Building and testing a physical structure	Lab Tours and Daktronics
Lunch break -	**Lunch Break**	**Lunch Break**	**Lunch break**	**Lunch Break**
Comparison of Scavenger Hunt results - In-class activity	Hands-on activity: Gas in the class: Ventilation calculations and graphing	Lab tours - ME department	Hands-on activity - Structures in the Human Body	Recap of scavenger hunt results - What do you see now?
Presentation on Engineering Design Process Presentation – Constructivism and the 5E Lesson Plan	Classroom activity - Where does it all go? - Estimating and Measuring water usage, mapping activity	Using technology to teach - computers and engineering design	Hands-on activity - What can we do better on our initial design?	Wrap-up activities
Developing and customizing curriculum (Group work)	Developing and customizing curriculum (Group work)	Developing and customizing curriculum (Group work)	Developing and customizing curriculum (Group work)	Post assessment - survey of participants engineering

Suzette Burckhard and Judy Vondruska organized the workshop that featured presenters from the Jerome J. Lohr College of Engineering: Chris Hay, Erin Cortus, Stephen Gent, Zachary Gutzmer, and Madeleine Andrawis. Each engineering faculty presented during a day dedicated to their engineering discipline, first by giving an overview of their profession, then a series of activities and tours chosen to give the workshop participants a broad view of a particular engineering field, as well as hands-on activities that could be adapted for classroom use. At the end of each day, teachers spent time reflecting on the day's activities by developing lesson plans as part of a team, using a constructivist teaching model emphasizing the 5E's: Engage, Explore, Explain, Elaborate, and Evaluate. On the first day of the workshop, teachers were instructed in the use of constructivism in teaching as well as the 5E Lesson Plan model[8]. Studies have shown the effectiveness of using Constructivism and the 5E model in teaching science[9-13]. At the beginning of each consecutive day of the workshop (Tuesday-Friday) teachers presented their team lesson plans to the rest of the group with discussion focusing on each aspect of the 5Es as well as the engineering concepts and science principles involved. Lesson plans were also placed on the Wiki site for later use.

Assessment of Workshop Effectiveness

We designed a short (10 minute) survey instrument to measure a change over time in workshop participants' general understanding of, and attitudes towards engineering. Broadly, the assessment served to evaluate participants' answers to three questions:

- What is engineering?
- What is the work of engineers?
- What are the differences between engineering and science?

The survey instrument was given the first and last day of the workshop. The survey, shown in Appendix A, consisted of thirteen short statements that required respondents to choose whether an activity was performed by mostly engineers, mostly scientists, both, or neither, and a number of open-ended questions. In general, the post-workshop responses indicated that participants:

- attribute more of a science focus to engineering than they did prior to taking part in the workshop [questions 2, 8, 12]
- recognize the work of engineers in creating solutions to problems [1, 3, 6, 7, 9, 10, 13]
- better differentiate the differences between the work of scientists and engineers [4, 5]

On each survey, a modern day scenario (development of the cell phone or the Hubble Space Telescope) was presented in which participants were asked to differentiate between the role of scientists and engineers in facilitating that scenario. An examination of the open-ended responses shows that respondents elaborated more in their explanations of engineers' involvement in developing and launching the Hubble Telescope, the scenario given at the end of the workshop. Participants provided shorter and less nuanced answers in the pre-workshop scenario about the advent of cell phones.

The last two sheets in the Excel file represent the last two questions of the post-workshop survey and are a self-report on how their thinking changed as a result of the workshop. In general the responses indicated that the teachers believe they learned significantly from taking part in the workshop. Their responses to these two questions are multifaceted and fall into the following general categories.

- They have a much broader and deeper understanding of engineering.

  "I did not realize that engineering was as broad as it is. My perception of engineers prior to this week was that they largely worked with civil and mechanical components. I was surprised to see much of the same equipment and methods used in engineering labs as I am familiar with in biology, chemistry, and physics labs. Engineers are scientists."

- They have a better idea of how to integrate engineering into their science classes.

  "I have a better understanding of the processes used to test materials and how to use this knowledge to improve my curriculum to incorporate design criteria in the classroom."

- They better understand the role of science in engineering.

  "My understanding of engineering has increased tenfold. I really believe science and engineering are very much integrated and fit hand in hand."

Respondents were asked to complete this sentence for the post workshop only: "I used to think _____, but now I think _____."

Example responses include the following.

"I used to think engineers only made the products, but now I think that they have to use all of the disciplines of science and math to define the problem, to determine a hypothesis and then to design a solution to the problem."

"I used to think that engineering was a narrow field of study, but now I think it is very broad and inclusive. I used to think that engineering and science had a number of differences between the two. I now think that the two are in many ways one in the same."

"I used to think that I was strictly teaching science in my classroom, now I think I must also teach how they can use that science to solve problems in nature."

The workshop also employed an external evaluator to assess the effectiveness of the workshop by following up with the teachers in their classrooms and at the South Dakota State Science and Math Teachers' Convention, held each year in February. Results of this assessment showed that the teachers enjoyed the workshop and found it useful for the majority of the activities and incorporated several engineering-related activities into their science classrooms throughout the school year.

Lessons Learned

The results from the workshop showed that participants experienced a change in understanding of engineering and how they could incorporate engineering into their classrooms. Based on feedback during the summer workshop and the report from the external evaluator, some changes were made in the format of the workshop funded in 2014. The number of tours was reduced since teachers could not easily share those experiences with their students, more hands-on activities were included, and some background discussion of content and theory was added to make sure all workshop participants started the activities with a similar background. The open-ended response section on the survey instrument was changed to better reflect the common experiences of all participants and the same scenario was used in the pre- and post assessment to allow for better comparison of results.

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Appendix A, Workshop Survey Questions

Part 1

Listed below are a series of statements that may best describe an attribute of the work of engineers, and an attribute of the work of scientists, and an attribute shared by both, or an attribute of neither. Please circle the option to which you believe the statement best applies.

1. Apply knowledge to solve practical problems:
   Engineers Scientists both neither
2. Understand the nature of the universe:
   Engineers Scientists both neither
3. Creating new things
   Engineers Scientists both neither
4. Create new knowledge
   Engineers Scientists both neither
5. Apply knowledge to solve theoretical problems:
   Engineers Scientists both neither
6. Make existing things work more efficiently
   Engineers Scientists both neither
7. Likely to be concerned with cost/benefit analyses
   Engineers Scientists both neither
8. Apply the scientific method
   Engineers Scientists both neither
9. Most likely to be blamed for the gulf oil spill
   Engineers Scientists both neither
10. Finding solutions to problems
    Engineers Scientists both neither
11. Utilize the tools of science (e.g., measurement, hypothesizing)
    Engineers Scientists both neither
12. Utilize guesswork in finding solutions
    Engineers Scientists both neither

Part II
Please write a brief summary of the <u>similarities</u>, if any, between science and engineering.

Please write a brief summary of the <u>differences</u>, if any, between science and engineering.

Part III
Please read and then respond to the following scenario:

Cell phone development: On January 13, 1946, the comic strip Dick Tracy showed the main character with a 2-way Wrist Radio which was later upgraded to a 2-way Wrist TV in 1964. Today, most adults have a cellular phone or smart phone that mimics and in cases exceeds the many of the features shown in the original comic strip. In December, 2011, there were 331.6 million cell phone subscribers in the $169.8 billion wireless industry.

Describe the role of engineers in facilitating the proliferation of cell phones today.

Describe the role of scientists in facilitating the proliferation of cell phones today.