AC 2010-1516: BROADENING THE APPEAL BY CHANGING THE CONTEXT OF ENGINEERING EDUCATION

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Broadening the Appeal by Changing the Context of Engineering Education

The diversity of the engineering student body as well as engineering professional populations has not changed significantly over the past twenty-five years. Although many efforts have been put in place, and have been shown to have a positive effect, the percentages of females and under-represented minorities have not increased significantly. This paper proposes an approach to engineering pedagogy starting in K-12 that presents engineering as a series of connected world challenges rather than a set of disconnected curricular areas. We create a structure to map the standard K-12 course of study to the *National Academy of Engineering Grand Challenges for Engineering in the 21st Century*. This framework allows engineering as a discipline to be used as an integrator in the learning of key engineering skills (mathematics, science, humanities, social studies, culture, design, etc.) rather than an add-on topic. Such a framework helps us improve how we talk about engineering among ourselves and to the general public. By expanding the realm of engineering into fundamental engineering skill areas, we are able to improve interest, excitement and pursuit of engineering as a plan of study and career in new ways. This effect is particularly needed among historically under-represented populations in engineering.

Introduction

In the current engineering environment we are faced with several distinct problems with respect to the future development of our workforce. One is that students graduating from our K-12 school system, although excellent in recall of fact, are not technologically literate in the broadest sense of the term[1]. (Note, that this does not mean that US students are not technically *capable*. Technological literacy equips an individual to confront life situations and enables them to identify the technological components of a situation and use technological concepts to make informed decisions. This involves understanding the nature and development of technology and being able to use technological concepts, including those of design and information technology, and to evaluate the results of this use.) Two is that, of the approximately 25% of students who go to college, only a small percentage of them are considering engineering. According to Al Soyster at the National Science Foundation, 6% of recent SAT test takers indicated an engineering preference. Three is that, of those students who do consider engineering, the percentage of underrepresented minority and female students has not changed significantly over the past 25 years, despite massive efforts to change those numbers.

For these, and many other reasons, a paradigm shift is needed in how we represent engineering to our potential students, their parents and their teachers. A recent National Academy of Engineering report, <u>Changing the Conversation</u> [2], enumerates several suggestions for redirecting the way that engineering is perceived, after first presenting the results of a study of how engineering is perceived by different populations today. Several results from this report are of extreme interest:

- The public does not have a negative view of engineers.
- Adults and teens believe that the work of engineers is rewarding and important, but they do not know what engineers do on a day-to-day basis.
- There is a strong sense that engineering is "not for everyone," especially not girls.
- The public understands engineering mostly in terms of intensive math and science, not teamwork, creativity, etc.

Most importantly, the report concludes that engineering should be portrayed as strongly connected to making a difference in the world, rather than in terms of personal skills and benefits. This potential message appeals to all subgroups of students and adults, but resonated particularly well with underrepresented minorities, specifically African American and Hispanic students and girls.

Another recent National Academy of Engineering publication looked at the penetration of engineering curricula and activities into the K-12 educational space. The report begins by outlining three core principles that engineering education in K-12 should address:

- Emphasize engineering design
- Incorporate developmentally appropriate math, science and technology knowledge and skills
- Promote engineering habits of mind

The report also enumerated several important engineering concepts that are important for K-12 students to understand including systems thinking, trade-offs, requirements, constraints and others. These topics are also a part of the defined technological literacy outlined in the draft NAEP assessment guidelines for a 2012 assessment in technological literacy[3].

The draft framework for the NAEP assessment breaks technological literacy into three sub-areas, including information and communication technology, design and systems, and technology and society. The importance of this definition lies in a vital error in semantics that has pervaded education so perniciously that it had appeared in congressional legislation such as No Child Left Behind. The K-12 educational arena tends to define technology as the information and communication technology used in the classroom, specifically computers, smart boards, the Internet, etc. This seemingly small mis-definition has led to a widespread misunderstanding of technology that is very limited and limiting. Whether K-12 students should be assessed on their understanding of technology (defined as anything human-made) and what technology is and is not capable of is very contentious, in part due to various groups debating based on differing definitions. If students are not taught to be truly technological literate, they lack the capacity to assess properly issues such as whether to allow irradiated foods, stem cell research, and global climate change. The necessary critical thinking skills to make up for this lack are easily instilled through K-12 engineering education.

One final item of concern is to discuss why engineering in K-12 education is important. An additional NAE report describes the existing K-12 engineering implementations.[4] The various disciplines encapsulated in the acronym STEM have many elements in common and many that are unique. To achieve a precise understanding of how they interrelate is critical to being able to use engineering as an underpinning of integrated instruction. Because engineers use science, mathematics and technology, engineering activities offer a way of teaching these three disciplines (together with social studies, language arts, etc.) in an integrated and authentic fashion.

In many instances, the various core subjects continue to be taught in isolation. Many teachers do not use updated teaching techniques, such as guided inquiry, in the classroom, because they are driven to teach a laundry list of facts by end of year assessments. This means that relevance and application are all but unachievable in the K-12 classroom in many instances. In addition, time pressures sometimes make the coverage of topics and goals that are not tested an impossibility.

Engineering naturally integrates various core disciplines. It is perhaps true that engineering is an underpinning of the other three subjects in STEM. It is a vehicle to bring rigor, relevance and context to the teaching of the other three subjects in an integrated manner. Using engineering as a vehicle allows core subjects to be taught efficiently, in a way that leads to more retention, to the ability to apply diverse knowledge to different situations, to synthesis, creativity and problem solving…all vital 21st century skills.

One of the hurdles to excellent teaching in science in particular, and maybe math as well, is the perception by students that they lack relevance in daily life. This perception is historical and pervasive. Teaching in K-12 through engineering can be a stealth approach to reaching children that haven't and aren't being reached in the teaching of isolated subjects now. Using engineering in the classroom can have the ultimate result that more kids learn more, better.

At the close of the 20th century, the National Academies produced a list of the greatest achievements of the century. These include:

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution

5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

Now the National Academy of Engineering Committee on Engineering's Grand Challenges, at the request of the National Science Foundation, has identified 14 areas of greatest need for engineering in the 21st century[5]. The challenges can be organized into four broad areas:

Enable humanity to survive:

1. Make solar energy economical
2. Provide energy from fusion
3. Develop carbon sequestration methods
4. Manage the nitrogen cycle
5. Provide access to clean water

Improve health:

6. Advance health informatics
7. Engineer better medicines
8. Reverse-engineer the brain

Improve security:

9. Prevent nuclear terror
10. Secure cyberspace
11. Restore and improve urban infrastructure

Contribute to the joy of living:

12. Enhance virtual reality
13. Advance personalized learning
14. Engineering the tools of scientific discovery

These engineering problems contain issues relevant to many aspects of the Standard Course of Study(SCOS) used to construct daily lessons in schools in North Carolina. The Standard Course of Study is defined by the State Department of Public Instruction, with input from national standards and customized to perceived needs of the state. For example the content standards for the National Science Standards are summarized as follows [6]. In perusing these topics, one begins to see that the grand challenges have application to several at a time.

- Unifying concepts and processes in science.
    - Conceptual and procedural schemes unify science disciplines and provide students with powerful ideas to help them understand the natural world. Because of the underlying principles embodied in this standard, the understandings and abilities described here are repeated in the other content standards. Unifying concepts and processes include
    - Systems, order, and organization.
    - Evidence, models, and explanation.
    - Change, constancy, and measurement.
    - Evolution and equilibrium.
    - Form and function.
- Science as inquiry.
    - Understanding of scientific concepts.
    - An appreciation of "how we know" what we know in science.
    - Understanding of the nature of science.
    - Skills necessary to become independent inquirers about the natural world.
    - The dispositions to use the skills, abilities, and attitudes associated with science.

Table 1: Physical science standards

LEVELS K-4	**LEVELS 5-8**	**LEVELS 9-12**
Properties of objects and materials	Properties and changes of properties in matter	Structure of atoms
Position and motion of objects	Motions and forces	Structure and properties of matter
Light, heat, electricity, and magnetism	Transfer of energy	Chemical reactions
		Motions and forces
		Conservation of energy and increase in disorder
		Interactions of energy and matter

Table 2: Life science standards

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Characteristics of organisms	Structure and function in living systems	The cell
Life cycles of organisms	Reproduction and heredity	Molecular basis of heredity
Organisms and environments	Regulation and behavior	Biological evolution
	Populations and ecosystems	Interdependence of organisms
	Diversity and adaptations of organisms	Matter, energy, and organization in living systems
		Behavior of organisms

Table 3: Earth and space science standards

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Properties of earth materials	Structure of the earth system	Energy in the earth system
Objects in the sky	Earth's history	Geochemical cycles
Changes in earth and sky	Earth in the solar system	Origin and evolution of the earth system
		Origin and evolution of the universe

Table 4: Science and technology standards

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Abilities to distinguish between natural objects and objects made by humans	Abilities of technological design	Abilities of technological design
Abilities of technological design	Understanding about science and technology	Understanding about science and technology
Understanding about science and technology		

Table 5: Science in personal and community perspectives

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Personal health	Personal health	Personal and community health
Characteristics and changes in populations	Populations, resources, and environments	Population growth
Types of resources	Natural hazards	Natural resources
Changes in environments	Risks and benefits	Environmental quality
Science and technology in	Science and technology in	Natural and human-induced hazards

local challenges	society	
		Science and technology in local, national, and global challenges

Table 6: History and nature of science standards

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Science as a human endeavor	Science as a human endeavor	Science as a human endeavor
	Nature of science	Nature of scientific knowledge
	History of science	Historical perspectives

In a typical elementary school classroom the day may proceed from one hour of literacy to one hour of math, lunch, recess, art or music, then one hour of either social studies or science, rotated through in multi-week intervals. There is little time to spend in inquiry or in tying the subjects to real-world applications, much less show how they can be used to make a difference. In middle and high schools, students typically move from classroom to classroom, studying one subject at a time. The problem of subject isolation is exacerbated.

Using the engineering grand challenges as a platform for teaching gives an easy entrée to the demonstration of how the subjects taught in schools can be used to make real substantive differences in the world. Consider the challenges of making solar energy economical, restoring and improving urban infrastructure, and managing the nitrogen cycle. The previous tables are highlighted in appropriate colors to indicate which of the pieces of the standard course of study could be addressed through the study of these issues. Notice how much of the science standards can be covered at least in part by just these three challenges.

In addition, the social studies standard course of study also overlays many of the challenges. Math can be addressed as students use statistics, geometry, and algebra to analyze issues, and language arts are always being addressed through reading background material, keeping an engineering notebook and communicating persuasive arguments.

Conclusion

The need for better STEM education that is more inclusive is well established. Recent publications from the National Academy of Engineering have emphasized that engineering holds promise for supporting a stealthy approach to this paradigm shift. The Grand Challenges identified by the National Academy of Engineering are a perfect platform to motivate and educate students about how their daily lessons have relevance to their own lives.

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