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P-12 Engineering Education Research and Practice

TAMARA MOORE
University of Minnesota
Saint Paul, MN

and

LARRY G. RICHARDS
University of Virginia
Charlottesville, VA

BACKGROUND AND CONTEXT

This special issue of ***Advances in Engineering Education*** explores recent developments in P-12 Engineering Education. It includes papers devoted to research and practice, and reports some of the most exciting work in the field today. In our Call of Papers, we solicited two types of papers: Research papers and Practice papers. The former would include research on P-12 student learning and on teacher education and professional development. The latter would focus on innovative practice by teachers and/or by engineers and university programs. However, papers in both categories had to be true "advances" with an applications orientation. We anticipated a few dozen submissions and a quick review process. We were surprised, delighted and overwhelmed by the response; we received over 60 abstracts by the deadline and several appeals after it. The first round of reviews narrowed our pool to about 30 authors who were asked to submit full papers for review. When the 14 final papers were accepted, we worked with the authors to adapt their articles to the unique features of AEE – in particular, its on-line presence and multimedia focus.

In this introductory essay, we provide a look at the emerging field of P-12 Engineering Education; indicate why precollege outreach is necessary; review the history of the field including the roles of the American Society for Engineering Education (ASEE) and the National Academy of Engineering (NAE), and reflect on where we are now and how the field may develop in the future.

NATIONAL CRISIS IN STEM

In the late 1950s and early 1960's, the Soviet Union shocked United States with two advances in space: the first satellite (Sputnik, 1957) and the first person in space (Yuri Gagarin, Vostok 1, 1961).

These events fueled the perception that the United States was behind in science and technology, and that significant action was needed to remedy the situation. Although there had been attempts to reform science and mathematics education in the 1950s, these events led us to consider a national agenda for science and mathematics education. For a few years, we had a sense of urgency and concern, and committed resources and attention to these fields. (Unfortunately, many feel that same sense is currently lacking, although the papers in this issue describe some very exciting, optimistic happenings.)

Over the years since, we have seen a large number of educational reforms and pedagogical experiments, but also continued reports critical of education at all levels but especially P-12 STEM education: *A Nation at Risk; Before it's too late!; Rising above the Gathering Storm*; and *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5.* Leaders and policy makers at all levels of government, industry, and education recognize the problems, and agree that fundamental changes need to occur to advance STEM education and encourage the pursuit of careers in these areas. President Obama has called for educating 10,000 additional engineers a year to meet national needs. (Indeed, enrollments in undergraduate engineering have, in fact, been steadily increasing according to the ASEE.)

http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

http://www.computerworld.com/s/article/9217624/Obama_We_don_t_have_enough_engineers_

http://www.asee.org/papers-and-publications/publications/college-profiles

Among the problems that have been repeatedly noted in STEM education, four stand out:

Poor performance of U.S. students on tests of mathematics and science

Reports about crises in our educational system are usually based on the performance of our students in comparison with other industrial nations on standardized test scores in mathematics and science such as TIMSS (http://nces.ed.gov/timss/index.asp). U.S. students consistently score lower in both categories than students from many other countries.

Insufficient numbers of students pursuing STEM careers

For many years, enrollment in engineering schools was consistently declining. We are on an upswing now, but are still not producing the numbers of engineers, scientists, mathematicians, and technologists we need. Most of the students pursing advanced degrees in engineering and computer science are not U.S. citizens. The problem will become worse with the expected wave of retirements among engineers and scientists. We will need to replenish the work force and hopefully expand it. We need more engineers and scientists now, and the problem will only get worse without effective intervention.

The problem starts well before college. Too few students pursue STEM fields in middle and high school, and this reduces the pool of eligible candidates for admission to college programs in these areas. Students are allowed to drop out of potential pathways to STEM careers because they "are not good at science or math." They are not encouraged to challenge themselves in difficult subjects. If we wish to influence career choices focused on STEM, we need to intervene early in the educational system.

Widespread Technology Illiteracy

We are surrounded by technology and live in a human-designed world largely created by engineers. Yet very few people understand the technologies they interact with every day, or have an accurate picture of what engineers do or how important engineering is to our lives. Most young people have no image of the engineer; they lack exposure to engineers or engineering unless a family member, friend or acquaintance is one.

One goal of introducing engineering into the educational system is to attract young people to these fields, but equally important is to provide a general understanding of technology and the nature of engineering. We need an educated, technologically sophisticated workforce, but we also need to enhance technological literacy in general. Those in leadership roles in industry and government make decisions about supporting and implementing science, engineering, and technology. It is essential that they be informed about the technological issues.

If we want to attract more students into STEM fields, we need a better public relations effort. But even those who pursue careers in law, medicine, business or politics should be aware of the role of engineering and technology in our lives. Innovation has been the cornerstone of America's economy, and it depends on continually increasing technological sophistication. And we know that an engineering education provides a solid foundation for going into medicine, law or business.

Lack of diversity in the profession

Since the 1960s, there has been a steady increase in the number of women attending college. Now the number of women earning college degrees exceeds the number of men. In many fields, there is gender parity. But not in the STEM fields. Although we need to have more women and minority representation in STEM, we have not been able to consistently attract them to these fields or retain them once enrolled. However, a few fields have made very good progress, Biomedical and Chemical Engineering in particular are now half women; in Industrial Engineering, the figure is about a third.

ENGINEERING EDUCATORS ADDRESS P-12 ENGINEERING EDUCATION ENDEAVORS

The solutions to these problems involve redesigning P-12 education. The forces for change will be both individual and institutional. Many engineers from industry and academe are involved with their local schools. Some industries send their engineers into schools to meet with students and teachers. Most engineering professional organizations have also been concerned with P-12 outreach including ASEE, the Institute of Electrical and Electronics Engineers, American Society of Mechanical Engineers, Society of Manufacturing Engineers, and Association of Computing Machinery. University faculty and students visit schools with projects and demonstrations designed to highlight engineering or science. There are many other P-12 programs some of which are cited by Richards [1] and Sullivan [2, 3], and several are represented in the papers in this special issue.

Massachusetts led the way in introducing engineering and technology into the P-12 education through its Science and Technology/Engineering Curriculum Framework. (http://www.doe.mass.edu/frameworks/scitech/1006.pdf). It was the first state to explicitly include engineering in its P-12 Educational Standards. A major player in formulating these standards was Ioannis Miaoulis, then Dean of Engineering at Tufts University, who engaged in the political and policy arenas to promote the standards [4]. He worked with the Department of Education, solicited support from industry leaders, and served as a technical advisor. The initial framework was implemented in 2001.

At Tufts, Ioannis established the Center for Engineering Education and Outreach (CEEO) with Chris Rogers and David Hammer as co-directors. The Center has become a major site of innovative P-12 research and engagement (http://ceeo.tufts.edu/). In January 2003, Dr. Miaoulis left Tufts and became President of the Boston Museum of Science. http://www.youtube.com/watch?v=cNAfnjqpueY

(http://www.mos.org/visitor_info/about_the_museum/presidents_welcome/presidents_bio)

Two major initiatives at the MOS have been the National Center for Technological Literacy and a curriculum - *Engineering is Elementary* developed by Christine Cunningham and her colleagues. The EIE Series of books show what engineers do and how they solve socially important problems. These are exemplary research and engagement activities and illustrate how museums and universities can help inspire young people to become engineers. As a whole, the work happening in Massachusetts is just one example of the many policy and research initiatives that are taking place across the country.

ASEE INITIATIVES

In 2002, ASEE established an Engineering P-12 Center to focus attention on this area, and to gather knowledge and resources about existing programs. Eric Iversen was ASEE's first P-12

Outreach Director and he set up a website with links to programs around the country. The website has since evolved into *Engineering Go for It*: an annual publication that is widely distributed to students around the country.

An ASEE K 12 Leadership Workshop held prior to the 2002 Annual Conference in Salt Lake City brought together 150 invited participants, and focused on the state of P-12 engineering outreach and where the field should be going. A report detailing the need for P-12 engineering education resulted from this workshop [5]. That report included six guidelines for P-12 Engineering Education engagement; such efforts should emphasize: hands-on learning, an interdisciplinary approach, expanded standards to include engineering and technology, focus on P-12 teachers, make engineers "cool", and develop partnerships.

ASEE has held a K-12 Workshop prior to its Annual Conference every year since 2002. After the first, the focus changed to demonstrating exciting practices for precollege teachers. The workshop is now very competitive with many more proposals each year than can be accommodated.

A new division

A group of ASEE members working on P-12 engineering education research and outreach started meeting at the Annual Conference to discuss the possibility of a new division. A constituent committee was formed; and the new division was rapidly approved and quickly grew to over 400 members. The division now has over 765 members, a very active membership, and robust a technical program at the ASEE Annual Conference. (http://k12division.asee.org/) [6]

Publication outlets

Although P-12 Engineering Education is an exploding field with many initiatives, there are few formal publication outlets. Most early papers were presentations in special P-12 tracks at the annual ASEE or Frontiers in Education conferences. At ASEE, these presentations were initially in established divisions such as Educational Research and Methods (ERM), Minorities in Engineering, and Women in Engineering. While those divisions still publish P-12 papers, the primary venue is now the P-12 division.

The National Academy of Engineering has commissioned a series of reports on P-12 Engineering Education identifying the problems and offering solutions [7–13] and three issues of their publication *The Bridge* have been devoted to articles about outreach to pre-college students (Summer 2006; Fall 2009; and Summer 2011).

Over the last decade, the *Journal of Engineering Education* has included articles on P-12 engineering education research. The *International Journal of Engineering Education* had two issues in 2007 (Volume 23 # 1 and 5) devoted to the K-12 and Pre-College Engineering Division and an issue in 2009 devoted to Outreach to Prospective Engineering Students (Volume 25 #3). Larry Genalo was a Guest Editor on all three issues.

Recently Purdue University has initiated the *Journal of Pre-College Engineering Education Research (J-PEER)* — the first journal dedicated exclusively to P-12 Engineering Education research. This electronic journal is published twice a year, and will emphasize pre-college STEM education.

This AEE Special Issue

Advances in Engineering Education is a unique journal. It encourages examples of practice as well as research, and encourages multimedia. We received enthusiastic support for our proposal for a special issue on P-12 engineering education. After an extensive review process, this special issue offers a diverse collection of papers. Of the 14 papers seven were identified as primarily research papers and seven as practice papers; however most have elements of both. Systematic research on the effects of K-12 engineering education is a recent development. Practice papers were expected to explain how the authors knew their contributions represented good practice. What kinds of evaluation data, observation data, etc. do you have and what does this tell you about your practice?

We have several papers describing unique programs: some relatively new, others well established. We also have three review articles that summarize existing literature or practice.

A BRIEF OVERVIEW OF THE PAPERS IN THIS ISSUE:

Hotaling, Lowes, Stolkin, Lin, Bonner, Kirkey, and Ojo have developed SENSE IT — a program in which middle and high school students learn how to construct, program and test an array of sensors. These sensors are placed in local rivers to monitor water quality. Over 1,700 students have participated in this program. The authors assessed student learning, as well as teacher and students perceptions and attitudes.

Zarske, Ringer, Yowell, Sullivan and Quiñones report on a longitudinal study of a successful partnership between a university and a Colorado school district. Eight elementary and middle schools supply candidates for the Skyline STEM Academy. This paper assesses the program's impact on student perceptions of engineering, preparation, and persistence as measured by attendance and retention.

Schnittka, Brandt, Jones, and Evans have investigated the use of a successful engineering teaching kit *Save the Penguins* in an informal after school program. They demonstrate the effects of their Studio STEM model on the motivation, beliefs and identification with STEM fields for the participants in their program.

Hynes studied six urban public school teachers as they taught a number of engineering design projects in their science and math classes. The teachers were introduced to the design process through the Massachusetts Framework for Engineering and Science. Morgan's concern was what engineering pedagogical content knowledge was reflected in their teaching; in particular, their understanding of the engineering design process.

Benenson, Stewart-Dawkins and White provided multidisciplinary design experiences for elementary students. They integrated engineering, art, math, science, and literacy into lower income, primarily minority K–5 schools. The design and build activities focused on cars and gadgets, and introduced key concepts from science and math. The students documented their activities, designs and reflections. The level of understanding demonstrated by these students is quite impressive.

Cogger and Miley have a middle school curriculum based on Massachusetts Educational Frameworks that spans several grade levels. It provides students more extensive exposure to engineering than most programs; they acquire over 60 hours of experience with engineering. This paper describes the implementation and assessment of a wind turbine design project.

Gilbuena, Kirsch and Koretsky describe their *Virtual Chemical Vapor Deposition (CVD) Laboratory Project* which allows high school students to simulate manufacturing processes in the integrated circuits industry. Over 600 students from five different high schools have completed this program since 2008.

Ryder, Pegg, and Wood review a project based summer workshop for 11th and 12th grade students. Students complete design projects and take courses from a variety of engineering disciplines. Started in 1965 at the University of Idaho, this is one of the longest running K 12 engineering outreach programs in the country.

Williams, Igel, Poveda, Kapila and Iskander have implemented science and mathematics activities built around LEGO Mindstorms. They have developed science and mathematics activities for elementary, middle and high school, including units on *Mechanical Advantage*, *Acceleration due to Gravity*, and *Fluid Flow Rate* and *Measurements & Accuracy*, *Pi-What is it?* and *Means, Modes, and Medians*. Their work builds on the ideas of Seymour Papert on how children learn complex concepts.

Veltman, Davidson, and Deyell developed robotics workshops aimed at making engineering and computer science attractive and accessible to young women. They employed two platforms, PicoCrickets and MindStorms, to bring art, engineering, and storytelling into design projects based on three themes. These personalized projects appealed to both genders.

Berland, Peacock and McKenna explored high school teachers and students' use of, and perceptions of the value of, engineering notebooks. They interviewed teacher and students and examined the notebooks from a sample of students in each class. The expectations and requirements of the teacher proved to be the dominant factor determining the content and usefulness of the notebooks.

Mendoza and Cox review the research literature in P–12 engineering education from 2001 to 2011. They reviewed over 50 publications and classified them based on seven dimensions. The results are organized into a matrix that allows the reader to identify papers of interest.

Strobel studied the approaches community colleges in the NSF Advanced Technological Education program are taking to promote P–12 engineering and technology education and how ATE representatives assess the effectiveness of those initiatives.

Carberry and Ohland review the role of learning-by-teaching in a variety of engineering education contexts including NSF GK-12 fellows programs and service learning EPICS

We hope you enjoy these papers, and we wish to thank our many reviewers who volunteered their time and expertise to make this special issue possible. And you should know that AEE welcomes submission of P-12 Engineering Education papers for future issues of the Journal.

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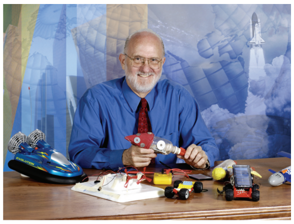
GUEST EDITORS

Tamara Moore is an Associate Professor in the Department of Curriculum and Instruction in the College of Education and Human Development at the University of Minnesota. She is Co-Director of the STEM Education Center, which focuses research on STEM integration in the K-12 classroom. She earned her Ph.D. in Engineering Education from Purdue University and is a former high school mathematics teacher. She has an NSF Career Award on Implementing K-12 Engineering Standards through STEM Integration and a CCLI grant on improving engineering students' learning strategies through models and modeling.



Larry G. Richards is a Professor in the Department of Mechanical and Aerospace Engineering at the University of Virginia. He has been involved in engineering and computing outreach activities since 1982. For the past ten years, he has brought Engineering Teaching Kits (ETKs) into middle school science and mathematics classes through the Virginia Middle School Engineering Education Initiative (VMSEEI). He is active in the K-12 and Pre-College Engineering and Educational Research and Methods Divisions of ASEE, and is a Fellow of ASEE.