ENHANCING THE EARLY AWARENESS FOR ENGINEERING AND TECHNOLOGY CAREERS – PROACTIVE LINKAGE WITH K-12 SCHOOLS

R. Radhakrishnan

Department of Civil & Environmental Engineering

A. Anil Kumar

Departments of Electrical Engineering and Physics
Prairie View A&M University

ABSTRACT

This paper calls for a proactive involvement of college faculty in engineering and science to enhance the early awareness and preparation of middle and high school students for the engineering and technology careers of tomorrow. It is stated often that, the society that the school and college students will graduate into is transforming from an information age to a conceptual age, and demands skills well beyond the traditional preparation that has characterized engineering education since World War II. On the other hand, in most engineering and technology departments concepts and techniques are still taught in fragmented courses whose relationship to each other, to the engineering process, or to the society, is generally not clear until the senior year, if ever. The implicit assumption seems to be that engineering is a set of topics engineers “need to know,” leading to the feeling that an engineering education is simply a collection of courses. The result is fewer students motivated to pursue engineering careers, and even those with a limited perspective. In this paper we report a comprehensive and systemic approach to design and implement a multi-pronged effort that involves exposing students to future careers, training teachers in chemistry, mathematics and physics, aligning the curricula between schools and colleges, and providing supplementary materials to be used in the schools. Such a proactive approach, concentrating on “advanced” skills of reasoning, problem solving, comprehension, and hands on activities, should have a better potential towards preparing students for college and hence for successful careers in engineering.
Introduction

The State of Engineering Education in the U.S.

Recent studies show that U.S. 12th graders performed below the international average for 21 countries on a test of general knowledge in mathematics and science. In an advanced mathematics assessment administered to U.S. students who were taking or had taken pre-calculus, calculus, or Advanced Placement calculus and to students in 15 other countries who were taking or had taken advanced math courses, eleven countries outperformed the United States, and four scored similarly. No country scored significantly below the United States. The results of such performance in high schools leads to the production of low number of technically qualified workforce.

The following statistics are fairly representative of the state of high school education in the U.S.:

- 70% high school graduation rate; significantly lower for Black and Hispanic students
- 34% college-ready graduation rate
- 30% of 1st year students required to take remedial courses
- 40 – 45% of recent high school graduates report significant skill gaps – for college and for work
- Faculty and Employers report that 40 - 45% of high school graduates are unprepared
- The U.S. ranks 16th in the high school graduation rate among the OECD (Organization for Economic Cooperation and Development) countries.
- Of the students polled 48% of students who have not gone to college and 31% of who are in college said they wished they had taken more math courses in school.
- These percentages were 41% and 32% for science.

With reference to Texas, the low number of Texas high school graduates qualified to enter university engineering programs exacerbates the engineering shortage. Although the number of graduates from Texas public secondary schools is growing, only 41% of high school graduates complete the Texas Education Agency’s Recommended Curriculum that contains the minimum math and science courses necessary for technology careers. Fewer graduates, perhaps as few as 5% of high school graduates, complete calculus, chemistry, and physics courses preparing them for a university engineering education.

More specifically to engineering, the freshman enrollment in all areas of engineering showed a steady decline during 2002-2004: 97,817 in 2002, 97,170 in 2003 and 96,978 in 2004. According to the College Board, the total number of students who graduated from high schools in all of U.S. is 3,118,689. Of these, 1,212,278 entered four-year colleges, amounting to 39%. Combining these numbers, the percentage of
students enrolled in engineering programs in 2004 seems to be around 8% which, in our opinion, does not provide a sufficiently broad pipeline for recruiting and graduating adequate number of engineers to meet the workforce needs of a new century. While the number of scientists and engineers who graduate from Indian and Chinese universities is increasing, U.S. universities are awarding fewer degrees in science and engineering every year, and many of them go to international students\(^5\).

**Public Attitudes Towards Engineering**

While there seems to be a generally favorable attitude towards engineering as a profession, answers to questions regarding one's future as an engineer seem to be lot less enthusiastic\(^6\). For instance, less than 50% agreed that they would have no problem in finding a job with an engineering degree. 45% agreed that having an engineering degree would outweigh the advantages over the disadvantages. Only 35% agreed that a career in engineering leaves time for family and leisure activities.

**Efforts to Alleviate the Situation**

While there are many attempts to alleviate this situation, there is general concern that, despite decades of reform, massive infusions of funds, aggressive efforts by policymakers, and the strong commitment of educators, there is no significant improvement in academic proficiency of high school graduates, closure of the achievement gap, and increase in high school graduation rates\(^7\) (Paying For Education, Texas Public Policy Foundation, co-published with the Milton and Rose D. Friedman Foundation).

As stated by Bill Gates, Microsoft Chairman, at the National Governors Assoc. Education Summit, February 26, 2005: “America’s high schools are obsolete. ... By obsolete, I mean that our high schools—even when they’re working exactly as designed—cannot teach our kids what they need to know. Training the workforce of tomorrow with the high schools of today is like trying to teach kids about today's computers on a 50-year-old mainframe. It’s the wrong tool for the times\(^8\)."

Compare this with for instance China, where the per capita income is $5,600, the government spends billions on a single crop: its scientists and engineers. So focused is this effort, The New York Times reports, that in one generation China has raised the proportion of its students in higher education from 1.3 percent to 20 percent. During 2005, China also produced more than 600,000 engineers and India 350,000 while the U.S. produced only 70,000\(^9\). While these numbers have been debated as to their accuracy, the consensus seems to be that high school performance does need to be strengthened\(^10,11\).
Questions To Be Addressed

The concept of Engineering Education in the 21st Century: Pipeline and Workforce begs the question of what engineering education for the 21st Century is, why and in what ways it is different from the previous times, and how we should provide that preparation so that today’s graduates can become tomorrow’s innovators and contributors to societal and economic developments.

More precisely, we believe that the following questions need to be addressed:

• How well prepared are our students for the world after high school?
• What does it mean to be prepared for college or the workforce?
• Are the state and national standards in science and mathematics adequate to meet these needs?
• Are these standards consistent with global expectations?
• Are these standards being properly implemented?
• Are there appropriate assessment processes and practices in place that ensure that the standards are being met?
• Is it realistic to expect all of our students to be prepared?
• Closing the expectations gap — what will it take?

Perhaps the single most important question is:

Are the science and mathematics preparations of a high school graduate on par with those of his/her international classmates in the first freshman semester?

Our Approach

Our approach calls for a proactive involvement of college faculty in engineering and the sciences to enhance the early awareness and preparation of middle and high school students for the engineering and technology careers of tomorrow. It is stated often that, the society that the school and college students will graduate into is transforming from an information age to a conceptual age\textsuperscript{12}, and demands skills well beyond the traditional preparation that has characterized engineering education since World War II. In our opinion, there needs to be a proactive approach, concentrating on “advanced” skills of reasoning, problem solving, comprehension, and hands on activities, coupled with involvement from the student’s parents, mentors, industry, academia, government, et al. In particular, the high school curriculum should be comparable in rigor to that in competing nations such as India, China and Korea.

There are several impediments to achieve this:

(i) Curricular requirements in the state curricula in the science and mathematics disciplines do not cover adequate number of topics or in adequate depth.
(ii) Little reinforcement, if any, in a given science course of concepts and applications from other science subjects.
(iii) Inadequate demonstrated relevance, of the topics taught to the student’s interests and careers.
(iv) High school teachers generally seem not to have the proper preparation in physical sciences and mathematics disciplines, hence cannot provide appropriate learning environment and technical experience to their students.

For American high schools to produce significantly higher number of globally competitive graduates, the science and mathematics curricula should be substantially enhanced. Table 1 shows typical science and mathematics subject coverage in a high school in Texas. This is in stark contrast to India, for instance, where all the science subjects and mathematics are required for all the students in every year in the high school curriculum. Transforming the current high school curriculum to this level can only happen with the firm commitment of all the stakeholders (students, parents, school administrators, teachers, community leaders and the government) and requires time. Our contention is that the current high school curriculum can be significantly strengthened by designing and developing supplementary materials for teaching science and mathematics.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Science</th>
<th>Mathematics</th>
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</thead>
<tbody>
<tr>
<td>7th</td>
<td>General Science</td>
<td>Finite Math</td>
</tr>
<tr>
<td>8th</td>
<td>General Science</td>
<td>Pre-Algebra</td>
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<tr>
<td>9th</td>
<td>Integrated Physics and Chemistry</td>
<td>Algebra I</td>
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<tr>
<td>10th</td>
<td>Biology</td>
<td>Geometry</td>
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<tr>
<td>11th</td>
<td>Chemistry</td>
<td>Algebra II</td>
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<tr>
<td>12th</td>
<td>Physics</td>
<td>Pre-Cal or Calculus</td>
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Our approach is systemic in that it encompasses several relevant aspects of education. Many of the details are available at the physics website13-17.

Our approach is based on the three R’s – Rigor, Relevance and Relationships. Rigor refers to the breadth and depth of the subjects covered, relevance establishes the need for learning the different subjects and to the student’s interests and careers, and relationships refer to involvement by all stakeholders in the student’s development.

The following is a set of major activities to achieve this goal:

1. Student Awareness to Life in College and the Workforce:

   Conduct a series of sessions with students from grades 8-12 on career planning. Each session will consist of one of the following:
   - exposure to different careers – taken from the Bureau of Labor Statistics Handbook and other such documents;
   - presentations by professionals from colleges, universities and industry;
• workshop on the development of individual career plans (relevance established through self-discovery as opposed to being directed);
• workshop on “translating” available job requirements into required minimal preparations;
• “what if” scenario laboratories, where each student will explore possible evolutions of their careers starting with specific beginnings.

2. Teacher Training, Especially in Mathematics and Science

The training mainly emphasizes exposure to science and mathematics for teachers who are teaching out of their disciplines. The objective is to reduce the apprehension of these teachers so that they can be more effective in their classrooms. A typical training session consists of building a rollercoaster or a programmed Lego object or simulating a Martian scenario. Open-ended projects are assigned to or chosen by the teacher (or a team of teachers) that require a combination of knowledge from different science subjects.

3. Alignment of Curricula Between High Schools and Colleges/Universities

This is a major element in the overall curricular design. Several elements at the school level are difficult, if not impossible, to achieve owing to incompatibility in graduation requirements and college preparation requirements. For instance, the requirements for school graduation are based mainly on a standardized test while the requirements for entry into a university (especially into engineering and related fields) are generally a lot higher. It has been reported that over 30% of students entering college require remedial courses.

College/university faculty should collaborate with the schoolteachers to identify gaps in the coverage of science and mathematics materials, and design a curriculum that provides for a seamless transition to college.

4. Development of Supplementary Materials

We believe that this is a novel element in curricular enhancement. The objective is to demonstrate the integration of multiple disciplines such as the sciences and mathematics. Supplementary materials will be developed such that they will reinforce the concepts from one subject to applications in other subjects.

For instance, a student enrolled in Biology in the 11th grade needs mathematical concepts such as surface-to-volume ratios, and physical concepts such as mobility and friction. The same student who was enrolled in chemistry in the 10th grade needs simultaneous equations to balance chemical reactions. Hence, concepts and applications from biology, chemistry and physics while the student is taking algebra in the 9th grade as well as concepts and techniques from algebra as applicable to the sciences will reinforce each subject’s relevance in the understanding of others.
An example of such supplementary material is given below.

Students, either in horizontal or vertical teams from grade levels 9 to 12, will be assigned a “real life” project. Such a project might be the optimization of the path taken by a Martian Rover (a programmed Lego vehicle) to collect data from various locations on the simulated Martian terrain in the shortest time possible and with the least amount of battery power consumption. Each integrated project team (IPT) will be asked to explore the various levels and types of knowledge required to complete the project. Questions will be posed relating to the needed chemical reactions that would provide a longer battery life, needed changes in the experiment depending upon the nature and type of terrain, types of data necessary for collection and analysis, naming conventions and practices of locations on Mars, costs associated with such expeditions – getting there as well as operations on the planet, viability of chosen chemical reactions and other factors in an extreme environment as compared to that on earth, socio-political-economic aspects involved in such expeditions based on the history of the Space Shuttle and the International Space Station, and potential for space tourism, among others.

RESULTS AND ASSESSMENT

The proposed approach is too new to yield results for any significant assessment. However, our initial training sessions of teachers in one high school has been received with great enthusiasm, while motivating teachers from several other schools to contact us for setting up similar training sessions. Several groups of high school students from across the U.S. have also spent a part of their summer programs at Prairie View A&M University such as the Summer Transportation Institute (STI), the National Youth Sports Program (NYSP) and the Pre College Institute (PCI). The PCI in particular consists of multiple components ARTEC (Architecture Enrichment Concepts), BASIS (Business for Academic and Scholarly Inclined Students), MITES (Minority Introduction to Engineering and Science) and TAME (Theater Arts and Music Enrichment). A sample of the comments from students in these programs may be viewed at the Physics Department’s website.
Conclusions

This paper presented an approach to the proactive involvement of institutions of higher education in the development of middle and high school students. The approach presented here is a practical and viable approach since it can effectively supplement the ongoing efforts in the schools. It meets and delivers on the graduation requirements from high school not just in terms of the typical standardized tests but in terms of being competitive in the global arena. It also provides the appropriate foundation, and an ability to build upon that foundation, for high school graduates to pursue professional careers in engineering and technology. The approach, through the design of supplementary materials, possesses the necessary properties of customizability, scalability and evolvability towards a more globally competitive curriculum. While the various components of this approach have been parts of other programs across the U.S., we believe that this is the first time that several relevant components have been integrated into a systemic scenario that seems to demonstrate excellent potential for success, defined as a substantially increased number of high school graduates pursuing baccalaureate degrees. This expanded pipeline should also significantly increase the enrollment in engineering and technology disciplines thus contributing towards the alleviation of the workforce issues.

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R. RADHAKRISHNAN
Dr. Radhakrishnan is an Associate Professor of Civil and Environmental Engineering. Dr. Radhakrishnan is a registered Professional Engineer and a Fellow of the American Society of Civil Engineers. His interests include research in structural and transportation engineering, and the development of approaches to increase workforce in the transportation field. He can be reached at raradha@pvamu.edu.

A. ANIL KUMAR
Dr. Kumar is currently a Professor of Electrical Engineering and the Department Head of Physics, Prairie View A&M University. His research interests are in condensed matter physics and telecommunications theory. More recently, he has collaborated with high schools and community colleges in Texas in curriculum alignment, school redesign and teacher training. aakumar@pvamu.edu.