

Bringing Engineering into K-12 Schools: A Problem Looking for Solutions?

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Abstract - Increasing the presence of engineering in K-12 education has become a high priority. Most middle and high school students and many of their teachers still do not have a positive attitude towards engineering or do not really know what engineers do. How do we meet this challenge of bringing engineering into K-12 classrooms? Two different approaches can be visualized for bringing engineering concepts and principles to these populations, introducing engineering as a “stand-alone” subject in the schools, or integrating engineering concepts and applications into the different content areas in the curriculum. Curriculum materials and instructional strategies are available for either approach. However, there are also issues to be considered for each approach that are common to both approaches. It is important to understand both the scope and the constraints of these intertwined issues. This study examines the two approaches within the context of these issues, including:

- Working within National and State academic content standards in various content areas including technology.
- Clarifying teacher certification and qualifications in the different states.
- Recognizing the need for appropriate quality teacher preparation programs.

Index Terms - engineering curriculum, Primary and secondary education; Teacher training.

INTRODUCTION

Engineering plays a major role in shaping the world today. Yet many bright, capable students choose not to pursue sciences in high school, and therefore have no opportunity to enter high paying engineering and technology careers [1]. Engineering appears to be invisible to students. Many secondary school students lack an understanding of how almost everything they use is dependent on various forms of engineering. They also are unaware of the benefits that engineering provides people in their daily lives. Yet all around us, from developing consumer goods, building a network of highways, air and rail travel, to creating artificial devices such as knees or hearts, the merger of science, mathematics and technology, better known as engineering, benefits people and makes the world we live in possible.

Engineering has long been recognized as a source of innovation and a significant driver of national economies. Increasing the technological literacy of the student population ultimately leads to a greater percentage of students qualified to pursue engineering studies, an increase in practicing engineers, and a more technologically literate workforce overall, all of which will positively impact a nation's economy and standard of living.

In the United States, as in other nations, there has been a growing interest by higher education institutions to bring engineering and technology principles and applications to the secondary school classrooms. Technology education programs have been developed and implemented both nationally and at local levels [2-4]. Programs for science teachers have included training and curriculum development that integrates engineering applications with scientific principles has been reported [5-10]. Many of the efforts have attempted to align the content of the curriculum materials and activities with academic content standards [5-7, 9-10]. Exposure to engineering principles has been extended to include pre-service teachers [11-13].

There are several factors that impact student interest in the technological fields. Students lack knowledge of the impact of engineering on society, and they are unaware of career opportunities in the engineering fields. Many students are not exposed to topics in these fields at all during their K-12 studies because their teachers have not been trained in incorporating these topics into their programs. In addition, the curriculum materials need to fit the instructional classroom needs of the teachers by addressing the content standards in science and technology/engineering. Although curricular materials are becoming more available in the technological fields, most do not appear to consider the issues that could hinder or facilitate their adoption into K-12 classrooms.

This paper examines these issues in order to help to understand both the scope and the constraints involved. Curriculum materials and instructional strategies are necessary, but they are not sufficient. Also necessary is adequate new teacher preparation, training of the current teacher population and the recognition of the pressure on teachers to align their instruction with the academic content standards so that students are prepared to demonstrate achievement of the standards through statewide assessment tests. As a result of their study, Fadali & Robinson [14] also considered the existence of these problem areas. In addition,

Anderson-Roland and her colleagues [6] examined the issues and concluded that the system of education as well as the pressure to implement academic content standards and associated high-stakes state-wide assessments, were barriers to the degree that science instruction and the curriculum can be changed or modified. This paper is intended to initiate a forum for the examination of these intertwined issues that should provide the broader perspective necessary to increase the presence of engineering concepts into the K-12 classrooms. The term “technology” as used in the United States National Science Education Standards [15] implies the design, engineering, and technological issues related to conceiving, building and maintaining useful objects and/or processes in the human-built world.

INCORPORATING ENGINEERING INTO SECONDARY SCHOOL CURRICULA

Two approaches provide educators and schools with the flexibility to adopt either an engineering curriculum or integrate selected curriculum materials into other subject areas such as science. The incorporation of engineering in technology education curricula focuses on existing or planned pre-college engineering and technology programs. These programs provide a strong mechanism for incorporating cohesive, level-appropriate engineering experiences for K-12 students. Typically, students enrolled in these programs are more interested in engineering and technology than their peers, and are strong candidates to study engineering as undergraduates. Incorporating engineering and technology in such programs reaches an important target audience. The second approach incorporates engineering topics into existing science and mathematics courses. Integration of engineering principles into science instruction, and presented through problem-solving inquiry/discovery pedagogy can stimulate students as well as enable them to recognize a direct link between their course work and the tasks performed by engineers in the real world [8]. When engineering and science are taught in tandem, they extend and reinforce each other. Unlike the engineering and technology curricula approach, this strategy can reach all students, not just those in pre-engineering and technology programs.

1. A Complete Engineering/Technology Education Curriculum

Efforts to implement this approach have been driven largely by the standards developed by the International Technology Education Association (ITEA) [16]. An engineering/technology education curriculum is usually a set or sequence of courses at the secondary school (middle school and high school) level, usually offered as an option for students planning to pursue engineering or engineering technology as a career goal. In addition, such programs are usually combined with college preparatory mathematics, science, and liberal arts courses in a high school program that are aligned with a state’s academic content standards in perceived subject areas. Engineering/technology curricula are available at the national level (e.g., The Infinity Project

[2]) or initiated as a “grass-roots” program by educators, such as the Madison (Wisconsin) West High School Engineering program [3], who have identified specific needs for the population they serve that cannot be met by a national curriculum. Cardon [4] has inventoried the diversity of programs at the secondary level in the state of Michigan. Usually, such courses will introduce students to concepts of engineering and engineering design and applied to several areas of the engineering field, such as biomedical, construction, electrical, mechanical, or process engineering. Lewis [17] has reported on the results of a survey of State Supervisors of Technology, to find out how widespread is the implementation of “pre-engineering in technology”.

2. Integrating Engineering into the Science Curriculum

Engineering is a practical mode of inquiry that directly addresses the issues people confront on a daily basis. Hence, science can be viewed as proposing explanations for questions about the natural world, while engineering proposes solutions for problems of human adaptation to the natural world. Instruction can emphasize the interdependence of these two disciplines as well as clarify their differences. However, science teachers are not trained in the content and skills of engineering [1, 18]. They lack relevant professional preparation and experience that would prepare them to teach principles of engineering.

Many science textbooks fail to include engineering/technology applications of the science concepts presented in the textbook [14]. Most textbooks do not have any laboratory activities that allow students to apply engineering principles and design to scientific concepts. Students may use some of the engineering processes, e.g., identify problems or design opportunities, but they are usually limited to science activities/experiments that do not have real world technological applications. Only occasionally is an engineering activity found in the physics part of a physical science textbook, e.g., design and testing of a model bridge.

Curricular materials in support of the integration of engineering into science instruction have been made available through professional organizations such as ASME and IEEE, as well as universities [5-8]. Most recently, curriculum modules, under the umbrella of “TeachEngineering” (TE) have been made available through the National Science Digital Library [19]. However, many of these materials lack the accompaniment of professional development for teachers. Of the professional organizations, IEEE does provide local professional development for teachers on their curriculum materials. Further, there is a need to translate existing engineering curriculum units into standards-achieving lessons for enriching the science curriculum.

The National Science Education Standards (NSES) [15] supports a broad exposure to a variety of topics in science and teaching students to design a solution to problems and the relationship between science and engineering/technology. Science and technology is one of the standards at all grade levels. According to NSES, “The relationship between technology, engineering and science is so close that any presentation of science without developing an understanding

of engineering or technology would portray an inaccurate picture of science” (p. 190). In addition, the standards “introduce them to laws of science through their understanding of how technological objects and systems work.” Scientific investigations by students can be complemented by engineering-type activities that lead to a product. The national standards emphasize the students’ abilities to design a solution to problems and the relationship between science and technology. Loepp [20] did a comparison study of the M/S/T standards, demonstrating the parallel nature of the engineering design process, scientific inquiry and the problem solving process. But problem areas do exist in terms of inadequate teacher preparation in engineering principles and technology.

National Standards for Technological Literacy, STL, [16] promotes the study of technology in grades K-12 so as to encourage the development of technological literacy for all students. The expectation would be that states would adopt the STL and implement them as part of their state content standards. The existence of nationally developed standards, such as NSES published almost 10 years ago, have not, in general, been adapted or implemented by most states. Rather, the NSES has served to inform the development or adaptation of content standards by most states. But, while NSES specifically includes standards that address engineering concepts, many states have omitted engineering/technology education from their content standards. Engineering remains mostly unused as a vehicle to stimulate and engage students and teachers in the learning and teaching of science, so that students can achieve the skills and knowledge specified by the standards. Indeed, some states still do not even consider technology education as a critical body of knowledge for its students.

Teachers find themselves caught in the middle between state content standards and expectations for improved student performance on state required “standards-based” tests. Teachers will only be accountable for what is in the standards. In general, only concepts that are in the standards are taught in classroom instruction. So, if teachers are to make their new knowledge a part of the instruction for student learning in their secondary science classes, engineering principles and design must be a part of the state science standards. Hence, the importance of engineering principles must be emphasized in the achievement of the state standards. The fact must be accepted that if curriculum materials are to be considered, let alone implemented, they must reinforce state content standards, since student achievement (and the schools and districts) is measured in large part by student performance on the statewide assessments.

TEACHER TRAINING AND TEACHER PREPARATION

As previously stated, professional development in engineering curricula will be needed for teachers if we expect them to alter their teaching. The professional literature suggests that the traditional approaches of single topic workshops or infrequently scheduled curriculum planning days will need to be altered if teachers are to

receive the education and training recommended for standards implementation [21,22]. Teachers are not likely to change their teaching practice unless they are given the skills, knowledge, and confidence to do so. Comprehensive professional development programs are needed to address the new skills and knowledge teachers need for improved classroom teaching and learning. Such programs include:

- Long term effort,
- Technical assistance, as well as support networks,
- Collegial atmosphere in which teachers share views and experiences, and
- Focus on teaching for understanding through personal learning experiences.

The integrative nature of science and engineering lies in the fact that engineering and design also provides a systematic approach to problem solving in a real world context. Teachers should understand how engineering offers an effective context for providing real-world problem solving experiences in science by engaging students in problems that require them to assess a situation or object and then apply scientific skills and knowledge to solving the problem. There is an urgent need for in-service training for science teachers that include classes to increase their knowledge of engineering principles and to provide those teachers with the means of introducing engineering principles and design in their classrooms. The professional development of teachers should focus on the incorporation of engineering and design concepts into science curricula in ways that meet appropriate academic standards [23]. Several programs include different models of “teachers teaching teachers”, including teachers presenting lesson plans to other teachers at summer workshops [8], teachers collaborating with university faculty as workshop leaders [5], and teachers who become certified to become workshop leaders [10].

Increasing the presence of technology in the K-12 curriculum will require more qualified and better prepared teachers for technology programs as well as for other disciplines in which engineering concepts can be integrated. Since approaches to bringing engineering into the K-12 sector seems to fall into two categories, teacher preparation programs should also have separate pathways for training teachers, programs for training students to become teachers of engineering and technology, and modifications of programs for teachers of science so that they are prepared to integrate engineering into their instruction. Technology education, as a discipline, is relatively young. The rapidly increasing number of high school pre-engineering programs across the country is creating a shortage of teachers qualified to teach such courses. Programs such as the degree program at Michigan Tech [11], or the option to an engineering degree program [12], are two approaches to the production of qualified technology educators that can be emulated. These approaches have one component in common. They all involve the cooperative effort of a college of engineering and a college/department of education. Science education majors should be exposed to engineering so that they are provided with the means of introducing engineering into their classrooms.

ASSESSMENTS

Evaluations of curriculum and professional development have, for the most part, focused on implementation. As important as implementation is, it does not necessarily answer the key questions of effectiveness and impact. Evaluation studies are needed that are designed to measure both implementation and effectiveness. Such impact evaluation studies are intended to answer a bottom-line question—Does the curriculum or professional development activity raise student achievement? The design, implementation, and evaluation of successful staff development programs, of necessity, must accompany curriculum renewal efforts because new teacher practices are needed for students to meet academic content standards [24].

Knowing which curricula or lesson modules are effective and ineffective provides guidance for school superintendents, principals, and teachers who need information to make decisions that will improve instruction and raise student achievement. Curriculum materials must be effective in enhancing academic achievement, and can be implemented in diverse learning environments. An effective curriculum should show increased student engagement and student performance. Whether it is standards at the primary or secondary levels, or proficiencies at the undergraduate level, a program, or curriculum unit, or a course with measurable learning objectives, integrated with the instruction and the assessment, should be able to improve student outcomes demonstrating that the students have achieved the skills and/or knowledge defined by standards or proficiencies [25].

Assessment tools that have been developed and utilized include pre- and post-content testing [8], different versions of an attitude towards and knowledge of engineering survey for students in their classrooms, after the summer workshops on the introduction of engineering into science instruction [7, 10], and “Preparedness to Teach Surveys” [7] and “Concerned-Based Inventories” [26] for teachers, which was administered prior to the workshop, at the end of the workshop, and after specified periods of time. Improved student attitudes towards and knowledge of engineering increased in all cases and can be attributed to increased comfort level of teachers with engineering topics and increased knowledge level of the teachers [7, 10]. Results from the “Preparedness to Teach” surveys have shown that teachers felt better prepared to teach specific concepts after the summer program, and teachers reported a greater comfort level one year later after having integrated engineering concepts into their instruction [7].

SUMMARY AND FUTURE WORK

This paper contributes to the dialogue to determine how the presence of engineering can be increased in primary and secondary grade levels and how the science curriculum can accommodate pre-engineering education. Several areas of focus have been identified, including the development of curriculum materials and instructional strategies; teacher preparation of new teachers; training of the current teacher population; and evaluation of both the implementation and

effectiveness of materials and strategies. Schools of engineering should continue their leadership in this effort in partnership with the other stakeholders.

The National Science Resources Center [27] provides a possible model for involvement of all stakeholders in an effort to improve education. Of interest is the inclusion of parents (through parent organizations for example), as stakeholders. Improved curriculum, by itself, may not be effective in bringing students into an engineering career if teachers, guidance counselors and parents, are either negative or uninformed about engineering as a career. Knowledgeable parents have the ability to influence career decisions of students toward engineering programs [28].

What still remains is to assess the long-term outcomes of these efforts. Tracking of the effects on student populations should demonstrate the impact of students pursuing STEM careers. This will require the engineering education community to significantly increase its efforts in K-12 outreach, as well as to significantly enhance its levels of collaboration with faculties of education and science and the K-12 teacher population. The American Society for Engineering Education’s K-12 efforts in this area are an excellent start that positions it to take a leading role in nationwide outreach activities. It will also require greater interaction with the political entities that set K-12 educational standards. Industry must also play a significant role. As the ultimate employer of students, it should help to define the specific areas of and level of technological literacy it needs for its workforce. Industry must also help schools integrate these topics into new or existing curricula by supplying expertise, real-world case studies, and support to schools as they initiate these programs [29]. There is a tremendous amount of work needed, but the payoff of a workforce that is more technologically literate, and that ultimately includes more engineers to meet the challenges of the coming years, makes the effort both necessary and worthwhile.

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