2006-309: BRINGING ENGINEERING INTO K-12 SCHOOLS: A PROBLEM LOOKING FOR SOLUTIONS?

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

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:
1) Introduce engineering as a “stand-alone” subject in the schools.
2) Integrate 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.
  Is standards alignment merely a referencing of the standards in the lessons, or a process of relating learning objectives to the skills and knowledge being specified by the standards?
- Clarifying teacher certification and qualifications in the different states.
  In many states, certification is confusing and inconsistent (e.g., a chemical engineer is denied certification to teach chemistry).
- Recognizing the need for appropriate quality teacher preparation programs.
  Are there a sufficient number of teacher preparation programs to put qualified and knowledgeable teachers in our classrooms?

1. Introduction

Over the next few years the demand for engineers is expected to increase three times faster than for all other occupations combined [1] but the number of students pursuing careers in engineering is not increasing adequately to meet this demand. In fact the number of students completing baccalaureate degrees in engineering has increased very little over the last decade [2].

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 [3]. 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.

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 [4-7]. Programs for science teachers have included training and curriculum development that integrates engineering applications with scientific principles has been reported [8-19]. Many of the efforts have attempted to align the content of the curriculum materials and activities with state content standards [8-11, 15-19]. Exposure to engineering principles has been extended to include pre-service teachers [20-26].

There are several factors that impact student interest in the technological fields. Many students are not exposed to topics in these fields at all during their K-12 studies because K-12 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 state 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 [27] also considered the existence of these problem areas. In addition, Anderson-Roland and her colleagues [9] 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 National Science Standards implies the design, engineering, and technological issues related to conceiving, building and maintaining useful objects and/or processes in the human-built world.

2. Incorporating Engineering into Secondary School Curricula

The engineering community generally agrees on the importance of introducing engineering into secondary school curricula as a strategy for increasing student interest in engineering, and ultimately increasing enrollment of qualified students in engineering degree programs. 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 [11]. 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.

2.1 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) [28, 29]. 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., Project Lead the Way, PLTW [4], or the Infinity Project [5]) or initiated as a “grass-roots” program by educators, such as the Madison (Wisconsin) West High School Engineering program [6], who have identified specific needs for the population they serve that cannot be met by a curriculum such as PLTW, or the Infinity Project. Cardon [7] 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. Carnegie Mellon University has a robotics curriculum available on its website [30]. Lewis [31] 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”. The results for 19 states is summarized, and shows a diversity of implementation ranging from exclusion of technology education from graduation requirements, and non-existence in state academic standards to presence as electives in the curriculum to a coherent sequence of courses.

Koehler and her colleagues [32] have taken a different approach by developing a set of Engineering Education Frameworks. The Frameworks are meant to serve as guidelines for incorporating engineering and technology concepts in the high school mathematics and science curriculums, thereby promoting technical literacy. As such, they can become a very useful tool for increasing the presence of engineering in the high schools. However, while they recognize the barriers that need to be overcome to accomplish this task, no follow-up is provided as to how the frameworks would be or are being implemented.
2.2 Integrating Engineering into the Science Curriculum

A focus is needed on content included in currently available curriculum materials that creates connections between the science used in engineering applications in the real world and science curriculum standards for which teachers and administrators are accountable. 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. Essentially, engineering is a practical mode of inquiry that directly addresses the issues people confront on a daily basis. 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 [3, 33]. The United States teacher education continuum, in its current configuration, neglects pre-engineering education at the secondary school level [34]. Further, science teachers 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 [27]. 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. Teachers can design their own activities to give more engineering applications of the science concepts but without formal courses in their pre-service programs or in-service training programs that address engineering principles, they are unlikely to do so.

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 and teacher developed lesson plans [8-19]. Most recently, curriculum modules, under the umbrella of “TeachEngineering” (TE) have been made available through the National Science Digital Library [35]. 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 need for translation into standards-achieving lessons can be seen by an examination of the “TeachEngineering” curriculum modules. Developed for grades K-12, the NSDL includes “Searchable Standards-Based Lesson Plans” to provide teachers with lessons meant to engage students in the study of science applied to practical situations in the real world. The lesson plans are reported as correlated with National standards and selected state standards, and are said to be “easily adaptable to existing curricula.” An examination of some of the modules shows, in many cases, mismatches of the referenced standards to the lessons. When the instructional outcomes of the lessons are compared with the expected outcomes of the state standards, inconsistencies in student expectations can be identified. As such the lessons need further alignment to ensure or document student achievement of skills and knowledge specified by the standards.

3. Engineering within the context of achieving content standards
The National Science Education Standards (NSES) [36] 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. NSES calls for a student-centered learning environment that uses an inquiry-based approach. That is, it should actively engage students in asking questions and designing experiments to solve problems. Also, 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 [37] 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.

The organization of content standards in science is intended to develop the students' cognitive ability based on critical thinking and scientific reasoning. The ability to learn through inquiry is a basic skill needed to understand how science principles and concepts could be applied to engineering principles and design. Most engineering disciplines require a high level of proficiency in basic mathematics and science knowledge and skills.

National Standards for Technological Literacy, STL, [28] 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 [29]. 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. Hence, as a subject area generally not included in state assessments, the STL may suffer a similar fate as the NSES [29].

Typically, state content standards are designed to provide minimum competencies for high school graduates, and provide the scientific and technological knowledge needed for the modern society. Standards are meant to provide statements of what students should know and be able to do. They are not designed to prepare students with the upper level math and science concepts that are needed to enter directly into post-secondary engineering, technology, and science programs.

State standards are informed or derived from national standards, districts develop curricula from state standards, and teachers develop lesson plans for the classroom using the district curricula. 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. 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. Students who are taking the minimal science program for the state assessments will only learn what is included in the standards for which they will be tested. 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.

There is a perception in some quarters that content standards in science adopted by many states do not give the needed emphasis to technological design in the curriculum. Engineering and technology is a natural means of coordinating concepts in science with mathematics. The standards should emphasize the importance of engineering and technology in the fusion and coordination of science and mathematics contents. A recent study [27] examined how well the NSES supported the teaching of engineering and technology principles and design within the traditional science content areas, who found that in general the national standards do support the teaching of engineering and technology in the science content areas. But they also concluded that problem areas do exist in terms of inadequate teacher preparation in engineering principles and technology, and a lack of consistency between the national standards and standards adopted in different states. They also noted that most science textbooks lack activities and problems that use engineering principles.

It has been argued that the Massachusetts Science, Engineering & Technology Framework is probably unique and could serve as a model for other states [32], some of which currently are developing similar programs. Some states like Texas and New Jersey do have technology standards that touch on many of the topics in the Massachusetts document, but in Texas for example, it is separate from the science standards, frameworks [18]. The Massachusetts document is significant in education in that the term “engineering” is used throughout the document. This is not the case in New Jersey, for example, where the description of the standard for technology includes the term “engineering”, but is not used again in the actual document. Another aspect of the Massachusetts document is that the technology/engineering component is part of the statewide assessment in science (25%). Since it is part of the statewide assessment, it has a greater probability of coverage in the classrooms.

Now consider the framework in a bit more detail. It was previously stated that standards are meant to define that base of knowledge and skills that ALL students are expected to acquire during their K-12 education. The National Standards in the different subjects, e.g., Science, and Mathematics, were based on this interpretation of standards. Adoption of content standards by states across the country was largely based on such thinking, as well as being informed by National Standards. However, it appears that, at least in part, the engineering component of the framework for ninth and tenth graders was not done this way. According to a report from the Massachusetts Department of Education [38], “The standards (grade 10) were derived chiefly from the syllabi of courses being taught at several Massachusetts high schools.” (Page 2) These became “a complete set of standards set forth for a full-year course in technology education, a core set of which is designated to serve as the basis for an end-of-course assessment at grade 10.”
The technology items are apparently derived from the standards developed by ITEA [28]. Following this type of curriculum guide will meet the needs of students interested in engineering and technology. However, the Massachusetts Science, Engineering & Technology Framework is meant to define the learning standards that ALL students are expected to acquire. It would not appear appropriate to require that all students be as knowledgeable in the specific technologies at the depth detailed in this document. Very few political entities would want to have such requirements for all their students. Quoting a teacher from a magnet high school in a southeastern state (He was a participant in a recent summer institute for high school teachers.), “‘Requiring engineering’: I think this will be a difficult task. But I do know that my state copied *verbatim* the national physical science standards and inserted only one additional item (which does have some engineering ties.) So if a national presence could be obtained this might be a way to leverage individual states. Just thinking out loud here...”

The NJ Core Curriculum Content Standards (CCCS) [39] in science appear to adequately address the principles of engineering and technology, although the term “engineering” does not appear in the science standard focusing on technology. During a revision of the original standards, technology standards were also adopted in New Jersey, which includes the label “engineering” throughout the document. Technology remained in the science standards as an application of scientific principles in support of technology.

Since the adoption of the N. J. Core Curriculum Content Standards by the N. J. State Board of Education, there has been a flurry of activity by teachers, administrators, schools, and districts to have their instruction and curriculum aligned with the content standards. The typical response has been to compare the topics in the curriculum and/or text materials for a subject to the standards and indicators for that subject, and to list “applicable” standards/indicators for each topic in the curriculum or text. This type of behavior has been reported elsewhere [40]. An alignment with standards is not simply a match with the content part of the curriculum. Other major obstacles for the implementation of standards in science classrooms include teachers’ lack of knowledge about standards-based lesson planning, and the lack of specific guidelines for translating general recommendations into classroom interventions [41, 42]. In addition to content, instructional practices and assessment must be included [40, 43].

Teachers find themselves caught in the middle between state content standards and expectations for improved student performance on state required “standards-based” tests. Such state tests are not usually well aligned with state content standards as compared to assessments that are specifically designed to measure the knowledge and skills specified by the content standards. A study by [44] concluded that, although most items on state-wide assessments may map to some state content standards or performance indicators, such assessments cannot be considered as being aligned with the state’s standards since the collection of items that make up these assessments do a poor job of assessing the full-range of standards and objectives specified for student achievement. As a result, teachers are more likely to emphasize instruction that matches the tests rather than the standards.

Our work in New Jersey has revealed that the use of standards-aligned curriculum materials is necessary but not sufficient to achieve the standards [42]. Curriculum with topics aligned to
engineering standards would also not suffice. For students to achieve the standards there must be more than just a matching or referencing of topics of a textbook to standards. Alignment with standards must also include the assessment of student achievement of the skills and knowledge defined by the standards. Actual standards achievement requires altered expectations of student outcomes, a different way of planning lessons and a specific sequencing of learning outcomes so that expectations and learning activities relate directly to the standards and their indicators.

Teachers need an explicit protocol for planning standards-based lessons, aligning student work expectations and classroom assessments to the standards and the learning objectives of the lesson, and establishing criteria by which they can determine whether students have achieved the particular standard or indicator. Several of the curriculum efforts have reported developing similar procedures for relating learning objectives with standards and assessment of student performance [8, 9, 15]. However, the reported alignment of standards is mostly a referencing to standards only, and assessments generally do not measure student achievement of the learning objectives, or are not present at all.

An analysis of lesson plans “aligned with the standards” that are available in print or from websites shows one or more of the following problems for many of the lessons:

1. Too many standards selected for one lesson, or the wrong standard is chosen in relation to the selected curriculum materials. Grade level specific statements of the standards are not used. Identified standard is not related to the central concept of the lesson.
2. Stated learning objective is not related to the central concept of the lesson, or to the standard selected for the lesson. Objective is vague or describes general knowledge and not intended student learning.
3. The intended learning outcome (assessment) is not related to the stated learning objectives or the chosen standards.

As an illustration, an important and popular topic relating to engineering is that of the kinetic and potential energy of motion. This topic has been part of the curriculum for our Women in Engineering (WIE) Programs [45] and the O'Shea-Kimmel protocol [42] has been part of all lesson planning. In one such lesson available to teachers on the web, several of these problems are noted. Only one of the three objectives actually matches the activity of the lesson. The learning objectives for the lesson do not match the specified standards, and the standards do not indicate the specific knowledge that students should obtain at the appropriate grade levels. Nor are the standards or learning objectives aligned with the lesson assessment, which should measure students’ achievement of the objectives and the standards. As with most standards, the statement of the standard does not supply specific, measurable metrics or appropriate grade levels. However, standards typically include more specific statements for different grade level bands, such as: “describing, measuring, and calculating quantities that characterize moving objects and their interactions within (for example, force, velocity, acceleration, potential energy, kinetic energy).” This statement specifies the knowledge students in the grades 5-8 band should acquire, is relevant to a learning objective, and is one for which student performance criteria can be provided. Incorporating such measures would simplify the linking of the materials to required standards and would facilitate adoption of these materials.

In our WIE programs, we specify the following learning objectives in the lesson plan:

1. Students will define potential and kinetic energy in a laboratory investigation.
2. Students will apply the principle of conservation of energy to the interaction between potential and kinetic energy. Expected performance criteria include:
   • Determination of potential energy at various points along the swing of the pendulum.
   • Determination of kinetic energy at various points along the swing of the pendulum.
Although the accuracy of the measurements in this activity is a serious problem, the value for the kinetic energy at the point of maximum velocity of the pendulum can be calculated.

Finally, an examination of our State Science Content Standards shows:
   • All students will gain an understanding of natural laws as they apply to motion, forces, and energy transformations

and for the middle school band:
   • Building upon knowledge and skills gained in preceding grades, by the end of Grade 8, students will describe the nature of various forms of energy and trace energy transformations from one form to another.

O’Shea & Kimmel [42] have developed such a protocol, which is now being piloted in New Jersey and California. The protocol starts with the concept that is to be taught. One or more measurable learning objectives are identified for the lesson. For each learning objective the corresponding statement from the content standards are then specified. The activity for the lesson is examined to be sure that it provides the student the opportunity to acquire the skill and/or knowledge specified by the learning objective and the appropriate statement of the standards. Finally the expected student performance is described (a student behavior or work product) that will provide the evidence that the student has acquired the skill and/or knowledge of the learning objective and the statement of the standard.

4. 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 [46, 47]. Often, teacher training institutes and after school workshops are seen as ends in themselves: the planning and delivery of teacher workshops is assumed to be sufficient to produce changes in classroom practice. They typically lack an implementation component to assure new behaviors are seen in the classroom.

Schumm, Vaughn, Gordon, and Rothlein [48] suggest that 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 [49, 50]. Some of the identified factors that should be included in successful professional development programs include [43, 47]:
   • Long term effort,
   • Technical assistance, as well as support networks,
• Collegial atmosphere in which teachers share views and experiences,
• Opportunities for reflection on one’s own practice,
• Focus on teaching for understanding through personal learning experiences, and
• Professional development grounded in classroom practice.

The teaching of science should be centered on inquiry-based strategies that incorporate the solution of real world problems. 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. In addition, engineering principles and design are present in science standards for many states. However, in most cases, the segments of the standards dealing with engineering principles and design are likely to be the ones that are least familiar to K-12 teachers and are therefore those that are least likely to be implemented. There is an urgent need for in-service training for science teachers that include classes to increase their knowledge of engineering principles and design in their classrooms.

The professional development of teachers should introduce participants to technological content and resources that expand their science knowledge and their ability to access further knowledge. In addition, the content needs to focus on the incorporation of engineering and design concepts into science curricula in ways that meet the national and state science standards. A long term professional development program that exposes science teachers to engineering principles and design can lead to the infusion of engineering principles and design into existing science classes that can be continued year after year and last through and beyond the training period. Several different models have been reported, each of which incorporates one or more of the factors considered essential for successful professional development [43, 47]. Most of them consist of 1-3 week summer workshops, which include time for teachers to share views and experiences, and unstructured follow up experiences during the school year [4, 5, 8-19]. Several programs include different models of “teachers teaching teachers”, including teachers presenting lesson plans to other teachers at summer workshops [13], teachers collaborating with university faculty as workshop leaders [4], and teachers who become certified to become workshop leaders [5,17].

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 [20], or the option to an engineering degree program [21], are two approaches to the production of
qualified technology educators that can be emulated. Only recently has New Jersey revised its teacher certification code to authorize a “Teacher of Technology” endorsement. The College of New Jersey is currently the only institution in the state authorized to offer a Technology Education degree. New Jersey Institute of Technology (NJIT) is not currently licensed to certify teachers. But the University is now collaborating with Rutgers University-Newark Department of Education that allows students to earn their engineering degree at NJIT, while earning teaching certification from Rutgers University. All these approaches have one component in common. They all involve the cooperative effort of a college of engineering and a college/department of education.

Certification of technology education programs should be based on the “Standards for Technological Literacy: Content for the Study of Technology”. In addition to undergraduate teacher preparation programs in technology education, special efforts should focus on the current workforce, both teachers and other professionals, so that the pool of technology teachers can be expanded beyond the traditional undergraduate programs. These efforts might include graduate programs or sequence of courses that could be available both as a pre-service option as well as an in-service option.

The education of science teachers generally does not include courses that promote an understanding of engineering principles and design. There is a need for states to have teacher certification requirements and in-service training for science teachers that provide exposure of science education majors to engineering so that these teachers are provided with the means of introducing engineering into their classrooms.

Several universities are seeking solutions to this problem by developing a graduate course for both pre-service and in-service populations [24], or undergraduate “exploratory” courses that can meet the needs of the science education major as well as for engineering students who are still undecided about their career options [20,21,22,23,25].

5. Assessments

Curriculum materials are available for both technology education programs and for integration into other subject areas. A variety of in-service models have been developed. However, 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?

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 K-12 level, 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 [51].

Successful professional development also requires appropriate evaluations of the programs.
Traditional evaluations of professional development programs have been limited to participants’
reactions to the program, and participants’ learning as a result of the program [52]. A survey is
often used to measure teacher satisfaction with workshops with no follow up assessment of new
teaching practices. 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 state academic content standards [50].

Several of the reported models of professional development and curriculum development have
included some form of assessment of the training programs that goes beyond measures of
participant satisfaction with workshop experiences. In addition to open-ended opinion surveys
for the summer workshop, one project also included pre- and post-content quizzes [13].
Attempts were also made to collect longitudinal data for the teachers one year after the workshop,
but were unable to generate responses from the participants.

Several reports include assessments of impacts in the classroom by curriculum materials.
Measurement of content acquisition included pre- and post-content testing for a curriculum unit
topic for both an experimental class and a control class [11]. In this study the experimental
group scored significantly higher than the control group. Quality control criteria were also
mentioned, but not described.

Other assessment tools included 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 [12, 19, 34]. Improved student attitudes
towards and knowledge of engineering increased in all cases and can be attributed to increased
comfort level with engineering topic and increased knowledge level of the teachers. However,
there have not been any longitudinal studies showing that these programs achieve increased
enrollment in undergraduate engineering programs, nor are there studies showing any effect on
increased retention in engineering undergraduate programs for students who have participated in
these K-12 programs.

Boettcher and colleagues [17] also reported increased comfort level and knowledge by teachers
as a result of summer training programs. Hirsch and colleagues [19] developed and implemented
a “Preparedness to Teach” survey for teachers, which was administered prior to the workshop, at
the end of the workshop, and one-year later. Results showed 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.
6. Summary and Future Work

This paper contributes to the dialogue to determine how the presence of engineering can be increased in K-12 schools 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; using engineering topics to achieve state and national content standards; and evaluation of both the implementation and effectiveness of materials and strategies developed to address these areas of focus.

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 ASEE’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 state and national bodies 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. 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.

References

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