Teaching Engineering at the K–12 Level: Two Perspectives

By Kenneth L. Smith and David Burghardt

There must be a more direct infusion of appropriate mathematics and science with the unique technological content (tools, machines, materials, processes) for an effective engineering education program to exist.

1. ***A major shift seems to be occurring in the amount of interest and action being given by the engineering community to teaching about engineering at the K–12 level. Please describe what you see happening.***

SMITH: I believe the shift has come from technology education professionals who have held a long-time belief that we missed the opportunity to pursue a national focus on engineering education as part of the Technology for All Americans Project. While that initiative was a major challenge and excellent work, it should have been our call to arms for launching a set of national standards for **Engineering Education** for All Americans.

The arguments for such a movement have been clearly presented for the past ten years or more. Engineering as a valuable part of general education for all children is as easily defended as the science community defending their mantra, "think like a scientist" as a noble skill. Well, science, until applied to enhance the designed world through engineering processes and techniques, has limited value in my opinion. Knowledge is a good thing; however, knowing how to apply such knowledge skillfully to improve human existence is a more worthy goal.

The confusion over what technology education offers remains. There is great work being accomplished by the CATTS organization. Standards-based resources are being created that address content in technology education, mathematics, and science (MST). But I believe that the individuals who are calling for strong support for a national engineering education program, which I fully support, are correct and offer the next phase in the evolution of this dynamic content area.

BURGHARDT: There seem to be several organizations that are becoming important to this effort—the ASEE K–12 division, the National Center for Technological Literacy at the Boston Museum of Science, the National Center for Engineering and Technology Education (an NSF-supported center), the National Academy of Engineering, and Project Lead the Way. Within the engineering education community, more faculty are becoming interested in engineering education at the K–12 and college levels. This is in contrast to their emphasis on content disciplinary interests in years past. For instance, I have been teaching elementary and middle school teachers engineering design problem-solving methodology for the past ten years as part of a master's degree in STEM education at Hofstra University. Engineers in industry are also very interested in having a voice, in participating in the K–12 educational process. We have had excellent support from corporate engineers on a number of grants for middle and high school teachers. This support ranges from serving on advisory boards to actually participating in workshops with teachers and students. There is a tremendous desire to help, and in the process of learning to help, the engineering community (academic and corporate) is beginning to become aware of the multiple demands placed on teachers. I believe the desire to help has a multiplicity of sources, some stemming from the wish that more students would consider engineering as a career choice, others from the desire that students become more technologically able and literate whether or not they intend to be future engineers. There is a move in some states, such as Massachusetts, to have (and assess) engineering and technology standards K–12. The Boston Museum of Science is creating engineering curriculum materials for elementary school teachers. Certainly curriculum materials exist for middle and high school teachers that have an engineering influence, such as the middle school text Mike Hacker and I coauthored, *Technology Education—Learning by Design.* Project Lead the Way has taken a strong role in providing engineering/technology education curriculum material at the high school and now middle school levels.

2. *There is an ongoing discussion about what constitutes engineering education and what constitutes technology education. What is your quick perspective of the commonalities and differences?*

SMITH: The technological literacy standards project offers two significant features that serve both fields well. That is, the standards have been written to address what students should know and be able to do. This approach is solid and should be cherished.

I strongly feel that Chapters 5 and 6 in the standards document (*Standards for Technological Literacy: Content for the Study of Technology* (*STL*) [ITEA, 2000/2002]) offer the most direct connection to engineering education. These chapters focus on the concept of design and the abilities to apply the design process to create new products and systems. This is what the engineering community does for us. The process of design and engineering delivers the valuable resources humans use each day as defined in Chapter 7, the designed world technologies.

Both fields require a fundamental understanding of technological development and the impact that it has created for society. However, engineering education takes the issue of authentic application of science and mathematics to a much more sophisticated and real level. That is, the "engineering process" requires a deeper understanding and sophistication of mathematics and scientific principles in order to effectively design and construct a useful product or system. I suggest that the work done in Maryland as part of the 1993 Maryland Curricular Framework for Technology Education be explored further with respect to nine fundamental "core technologies" identified by the engineering community at that time. These nine core technologies offer a sound foundation of study throughout a K–12 engineering program. These core technologies could be included easily with ***Standard 2*** in the *STL* document—***The core concepts of technology***.

These fundamental technologies include: ***mechanical, structural, fluid, electrical, electronics, optical, thermal, biotechnical, and materials.***

This rigor in engineering education, especially in mathematics and science, would require a very different approach to teacher preparation. That presents the most significant difference between the two programs. Currently, technology education teachers are "unarmed" with respect to delivering a quality, rigorous, and challenging engineering program.

There must be a more direct infusion of appropriate mathematics and science with the unique technological content (tools, machines, materials, processes) for an effective engineering education program to exist. I believe the CATTS materials being developed using the Engineering byDesign™ approach have established a strong foundation for a new program—engineering education. The use of national standards in mathematics, science, and technology to develop instructional materials is essential for a successful engineering education initiative along with a fundamental course exploring the nine core technologies as described above.

BURGHARDT: I believe there are tremendous commonalities that lie in the study of the human-made world, such as the impact of technology on society and how it transforms society, technological literacy, and with design as a problem-solving technique. However, there has not been enough thought given to engineering design from a pedagogical perspective. I believe this problem-solving strategy can be effectively used from kindergarten to high school, though not all engineering educators may share this view. The major difference between the two disciplines relates to mathematics; not math as a content area, but as a way of modeling systems. In general, technology education practice has a "build and test" approach to design, while engineers want to develop physical models of the actual physical system, then create mathematical models that describe the physical models. This is much of what engineering education focuses on—engineering analysis, the creation of physical models, and expressing these models in mathematical terms. This allows for predicting system behavior and understanding the factors that affect performance. The actual physical design is tested, just as in the technology education approach, and its performance is compared to the theoretical model.

3. *Is there enough difference in what the engineering community is doing that would create a need for K–12 engineering standards that are different from* **Standards for Technological Literacy?** *Why or why not?*

SMITH: Again, I think the most direct solution for a meaningful and appropriate engineering education program is to generate a national standards document that blends "selected" standards in mathematics (NCTM), science (AAAS), and technology (*STL*) at all grade levels to ensure an appropriately rigorous and sophisticated program that helps students "think like an engineer." It is the process of DESIGN that engineers perform in their work that has such significant value for all Americans, even though most will not pursue a career in engineering. Most Americans do not pursue a career in mathematics or science, yet we have established the knowledge and skills in these domains as essential, especially at higher levels of sophistication. I ask, "Why?"

I believe it is more valuable to establish a content area that offers a reason to know how to apply appropriate mathematics and science in the solution of authentic and challenging problems facing humanity, not just continued acquisition of knowledge about the natural world. There must be a place in general studies that allows students to "put it all together." Such a place would be the engineering education classroom/laboratory.

BURGHARDT: I realize there is an effort within the engineering education community to develop K–12 engineering standards. I do not think this is wise. While the *Standards for Technological Literacy* document fails to address all the concerns of the engineering education community, it does address many of them. I think this could be an ideal time to revise *Standards for Technological Literacy*. *STL* does not address the engineering modeling concerns, does not link to math or science standards (as AAAS Project 2061 does), and there are inconsistencies in the organizational format that could be improved. The differences and commonalities could be melded into one document that would unite the engineering and technology education communities to build a broader base of support.

4. *Series of courses are now evolving that are mathematics-, science-, and technological literacy-based for the elementary through secondary level. Are those courses needed to stimulate and give practice to students thinking about being future engineers, technologists, architects, and more—or is some other type of course work needed?*

SMITH: I strongly believe that the current effort by the CATTS consortium, using the Engineering byDesign™ process, is a viable solution for instructional resources in engineering education. These materials have blended national standards in mathematics, science, and technology at appropriate levels of understanding. I have had the opportunity to participate as an author and reviewer of these new documents and find them to be worthy of critical review by professionals in engineering and education to determine the instructional value for a new program—engineering education. I believe this body of work to have significant merit.

These courses, when completed, could offer the best possible collection of materials to deliver a more rigorous, challenging, and exciting program for students in our schools. Of course, there is always room for editing and refinement of such materials, with constant updates as appropriate. I also encourage the use of ABET guidelines in the creation of these or future instructional materials.

BURGHARDT: I do not believe there is a research base to support the contention that K–12 STEM courses are needed to encourage students to consider careers as engineers and technologists, no matter how intuitive that appeal may appear. Certainly such research is needed, but in previous generations students considered these career paths without specialized courses. I would argue for teachers learning and having students use the engineering design approach to problem solving as a way of thinking. This allows for a link to core academic disciplines—math, science, and language arts—and a continuous connection to the designed, human-made world. This can be incorporated into the existing K–5 school day, a day already overcrowded with push-ins, pull-outs and non-academic, though important, agenda items. There is a lot of repetition in children's educational experience, especially when teachers use test prep questions as curriculum. Design can be introduced as a pedagogical strategy. At the middle and high school levels, integrative engineering and technology STEM courses could be useful in providing contextualization of mathematical and scientific concepts. The more engineering and technology education courses that are STEM-based, the broader will be the support base for these courses.

5. *How would you compare the student outcomes expected from engineering courses with what you would expect from a technological literacy course in our schools?*

SMITH: Student outcomes would be based on performance from the standards that would be established. As I mentioned, a new set of standards that combines mathematics, science, and technology has been used in the new CATTS documents. Assessment limits along with *unit* and *end-of-course* assessments have also been created with these resources.

Student expectations and performance would be based on this new collection of standards as identified in the various units found in each course. These units have been developed using the *Planning Learning* document from ITEA, which provides excellent direction for the "Big Ideas" in each unit. Continued use of the current ITEA *Planning Learning* resources combined with "selected" standards at appropriate grade levels from mathematics, science, and technology education would present a clear and direct description for student outcomes in a new engineering education program, K–12.

Currently, technology education programs in our schools reflect the *STL* standards only. I view this as a significant limitation. A viable engineering education program will require a math, science, technology **(MST)** synthesis with ABET guidelines from standards, instruction, and assessment of student work.

BURGHARDT: I think of these as two different types of courses; both are very useful and important educationally. I would describe technological literacy courses as ones discussing the history of technology in society, the impacts, good and bad, that technology has had, and discussing technologies from a "how it works" perspective. An engineering course could include "how it works" information, but in general would address technical content from a design and modeling approach. Engineering analysis would be an important element to the course, and there would be strong connections to math and science. There is a particularly strong connection to mathematics because of the modeling aspect.

6. *Would you expect the background of a person equipped to teach engineering-oriented courses to be any different than for technological literacy courses? Why?*

There is no doubt that if a math, science, and technology-based engineering education program were developed, the preservice and inservice requirements for instructors would have to change. I have always agreed with my colleagues who have felt our technology education teachers are not prepared to teach a comprehensive engineering education program. They are simply unarmed for the task. I have lobbied for a long time that our teacher preparation institutions rethink their approach and course offerings for preparing technology education teachers. This would be especially true if these institutions were to prepare engineering education instructors.

I believe a new model has to be developed. There are a few universities that are exploring this need. Johns Hopkins in Baltimore has an active group working to survey and move forward with a program description for Engineering Education as part of their Engineering School. In effect, this would offer individuals interested in engineering the opportunity to complete a rigorous new program with significant emphasis in mathematics and science abilities, combined with dynamic courses in materials, fluids, optical, structural, and mechanical systems (*similar to the core technologies discussed earlier*). Development of these courses would be based around standards in mathematics, science, and technology. The current *STL* standards would be used and valued, but the inclusion of mathematics (NCTM) and science (AAAS) must be addressed as well.

I continually encourage my current technology education teachers to pursue additional core subject endorsements via the Praxis II examination or course work at a local college for mathematics and/or science. I strongly believe this is essential for delivery of a rigorous and challenging program, certainly in technology education, but especially a new program in engineering education.

The benefits of multiple certifications for teachers in our fields are quite evident. As our nation tries to ensure highly qualified instructors in all content areas as part of NCLB legislation, every local school district must strive to encourage teachers to obtain as many certifications as possible, especially in the core subject fields. For technology education or engineering education, that must include mathematics and/or science endorsements. Hopefully, our teachers will realize this need and respond. I also hope our teacher preparation institutions will review their programs and make appropriate changes. We have so much to gain through this one strategy—more education and certification.

BURGHARDT: Yes, based on the differences in student learning outcomes as noted previously. The teacher needs a good analytical background so he/she is comfortable with modeling and predictive analysis. The overlap in teacher technology education and engineering curriculum is strong in the technological literacy area. However, the academic background of many technology education teachers does not include engineering predictive analysis, the background needed for modeling. There would need to be an increase in the mathematics requirements for technology education teachers as, in general, the current math requirements are not sufficient to teach them predictive modeling analysis.

Conclusion:

SMITH: There are many educators around the country who feel strongly that engineering education is a content area whose time has come and has been long overdue. I want to mention one such person, who presented his ideas in a recent article in *Science* Magazine, Vol. 311, March 2006. His name is Ioannis Miaoulis. He has a science background, but presents his interest in engineering education with great passion. I too share this passion.

Ioannis has led the way for engineering standards to be developed and adopted in Massachusetts. His campaign has moved to a national effort. He has led the way for a National Center for Technological Literacy, a non-profit organization with substantial funds to date, and has developed an elementary school curriculum and an engineering course for high school students. Ioannis states that his dream is "to have the human-made world be a part of the curriculum in every school in the country within the next decade." I share this passion and dream.

I believe substantial work has been accomplished towards this goal. However, much work remains to be done. I only hope a national focus will be embraced and fast-tracked into our schools. The dividends will be enormous for our place in a highly competitive global economy.

BURGHARDT: As we analyze the differences and similarities of engineering and technology education, the real focus needs to be on students and how we can improve their understanding of and appreciation for the technological world while deepening their knowledge in mathematics and science. A tall order, but one I think STEM-based engineering/technology education can meaningfully contribute to.

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