

2006-923: INFUSING ENGINEERING CONCEPTS INTO TECHNOLOGY EDUCATION

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Infusing Engineering Concepts into Technology Education

Infusing engineering-related concepts into K-12 level curriculum is a rather new initiative for public school teachers in the United States, especially those who teach technology education. Maurice Thomas, in a paper presented at the Mississippi Valley Technology Teacher Education Conference, stated that “Technology education has the opportunity to become a partner with engineering and benefit from their image, support, and political power. Many argue that we [technology education] would gain a great deal and lose little because engineering content fits comfortably with technology education objectives and content.”¹ Many technology teachers, however, wonder if this new initiative is viable for the future of the technology education profession, or that infusing engineering concepts into technology education is just a fad that will pass, especially since the field of technology education has existed on its own since the early 1800’s.

Currently there exists at least three camps of thought regarding the infusion of engineering related concepts into technology education:

1. Technology education should switch its entire focus to that of preparing a citizenry that is educated in a pre-engineering program similar to Project Lead the Way or a vocational-specific track for engineering;
2. Technology education should infuse engineering-related concepts into the existing technology education curriculum and courses as part of the general education of all citizens living in a technological world; and
3. Technology education should abandon the thought of infusing any form of engineering concepts into the curriculum.

Clearly there are varying perspectives regarding infusing engineering concepts or not into technology education. The authors of this manuscript subscribe to the second camp of thought (i.e., to infuse engineering-related concepts into an existing technology education curriculum and courses). Therefore, the purposes of this manuscript are to: (a) present initial findings regarding what engineering concepts should be incorporated into technology education; (b) explain how infusing engineering concepts into technology has occurred through the initial professional development work of a National Science Foundation-funded Center for Learning and Teaching grant; and (c) show how curricular items are developed that are standards-based, authentic, and relate to the mission of both engineering and technology education.

Technology Education and Engineering

The technology education field has had a long history of preparing teachers to engage students in a variety of applied technological activities. Historically, there has been a tendency for this applied emphasis to be disconnected from a clearly defined and well organized conceptual structure. In other words, activities have often been selected and designed more for their potential to engage students than for their ability to deliver concepts. As a result, the technology education field has suffered from a lack of well designed, standards-based curriculum. Merrill stated that “An engineering thrust may create a clearer case why technology education should exist in the public schools.”² There exists, however, a major stereotype that has to be overcome if engineering concepts are to be integrated into technology education, and for engineers to take technology education seriously. Greg Pearson, a Program Officer with the National Academy of

Engineering, made the following statement regarding common perceptions of the two fields of study. “Let’s face it, engineering is filled with elitists, and technology education is for blue-collar academic washouts.”³

It is not a new idea that engineering should be an emphasized component in technology education. Olsen suggested the inclusion of engineering concepts in industrial arts education in the late 1950s. Lewis summarizes the breadth of the effort to integrate engineering into the technology education curriculum.⁴ While the Massachusetts Department of Education (2001)⁵ has developed an extensive set of content standards for its own pre-engineering curriculum, Lewis documents that a variety of states are allowing students to take Project Lead the Way courses, a pre-engineering approach, as part of their technology education. However, Lewis also characterizes the pre-engineering emphasis as both a way to integrate STEM education thus improving student achievement and as a way of improving the perception of technology education among educators, and other professionals, from other academic disciplines.

In order to improve the level of acceptance that technology education can gain in the public schools and in order to more completely represent the essence of engineering as it relates to technology for the improved achievement of students, Wicklein (2004a)⁶ proposes infusing engineering design into the technology education curriculum more deliberately than it is currently included. He outlines basic, broad categories for the infusion of engineering design into technology education. In terms of those broad areas of engineering that should be infused into the curriculum he includes, “...narrative descriptions, graphical explanations, analytical calculations, physical creation” (p. 7). He also describes courses that might represent a technology education curriculum that infuses engineering design. The courses include, “Introduction to Technology, Engineering Graphics, Research and Design, Engineering Applications” (p. 6). *Included as essential in the curriculum are optimization, analysis, and prediction.* Wicklein also implies that students should take all of the science and mathematics courses that are available in high school.

Existing Efforts to Integrate K-12 STEM Education

Lewis has also done a comprehensive job of summarizing efforts within technology education to integrate the curriculum with engineering, science, and mathematics. Projects such as the Integrated Mathematics, Science, and Technology Project and the Technology, Science, Mathematics Integration Project are just two of many efforts to integrate STEM education that are headed by technology education professionals. However, there are also efforts outside of the field of technology education. Programs such as those in the Centers for Teaching and Learning⁷, supported by the National Science Foundation (NSF), are attempting, in some form, to integrate STEM education at the public school level. NSF funding has also included money for informal STEM education targeted at the K-12 and family levels. The Boston Museum of Science⁸ is one example of such outreach efforts.

In the face of the back-to-basics movement of the 1980s, there began a sequence of national content standards projects related to K-12 STEM education. Salinger describes the breadth of existing standards for STEM education and concluded that standards should cause cross curricular teaching and learning and that the standards should be geared toward higher levels of

achievement.⁹ He is not specific regarding what to teach, however, he strongly emphasized the need for curriculum integration among STEM subject areas.

Mid-Continent Research for Education and Learning (McREL)¹⁰ is an example of a U.S. Department of Education effort to provide standards for the integration of STEM and other school subjects. McREL is charged with creating reform in education through systemic initiatives, and its fourth edition of a compilation of school wide content standards provides, perhaps, one of the most comprehensive sets of standards available to teachers.

Curriculum and Evaluation Standards for School Mathematics

The first notable set of national standards was developed by The National Council of Teachers of Mathematics. It formed the Commission on Standards for School Mathematics¹¹, which developed broad standards for mathematics education in the public schools. The standards are grouped into large categories and a great emphasis is placed on developing the student as a problem solver as opposed to ones who memorize mathematical facts. The *Curriculum and Evaluation Standards for School Mathematics* emphasizes that “less is more” when it comes to freeing up enough time in the classroom to develop students who use mathematics reasoning and problem solving. A very refreshing feature of these standards is that an effort is made to emphasize the use of mathematics in other subject areas such as science and technology.

Science Standards

Beginning in the late 1980s and through the 1990s three notable sets of science education standards were developed. Two emphasized the importance of teaching technology and engineering in the science curriculum. The three projects are briefly described below.

- Scope, Sequence, and Coordination of Secondary School Science, developed by the National Science Teachers Association¹², did not directly call for the integration of science and technology, but it laid a foundation for later work in science content standards.
- *Science for All Americans*¹³ and the *Benchmarks for Science Literacy*¹⁴ developed by Project 2061 of the American Association for the Advancement of Science, called directly for curriculum integration of mathematics, science, and technology.
- National Science Education Standards, developed by the National Research Council¹⁵, also included standards that related to technology and engineering.

Standards for Technological Literacy

In 1996, the International Technology Education Association (ITEA), with funding from the National Science Foundation and the National Aeronautics and Space Administration began the Technology for All Americans project, which culminated in 20 standards, and their benchmarks, for technology education and other programs that aim to contribute toward developing technological literacy in the public schools. In 2000, ITEA published the *Standards for Technological Literacy: Content for the Study of Technology*.¹⁶ In addition to helping teachers develop curricula related to technology as it is broadly defined, these standards and their benchmarks call for students to understand a number of concepts related to engineering, including optimization, trade-offs, engineering design, and design skills and knowledge.

The development of the *Standards for Technological Literacy: Content for the Study of Technology* represented an important shift in emphasis toward positioning curriculum development, activity selection, and professional development around core concepts. Important concepts within the *Standards for Technological Literacy*, inter-connected with engineering, are problem-solving and design, the interrelationship between society and technology, technological capabilities, the inherent nature of technology, and the historical aspects of technology. Since the release of the *Standards*, the field has moved to align more closely with engineering. This shift has occurred for a variety of reasons including conceptual similarities between the content and practice base of engineering and technology education, engineering's growing interest in pre-university level involvement, and broad public support for engineering at the K-12 level.

In a Delphi study made up of a panel of experts in engineering and technology education, Dearing and Daugherty¹⁷ found that the top ten engineering-related concepts that should be infused into technology education were:

1. Interpersonal skills including teamwork, group skills, attitude and work ethic;
2. The ability to communicate ideas verbally and orally;
3. Working within constraints;
4. Ability to brainstorm and generate ideas;
5. Assess product design;
6. Troubleshoot technological devices;
7. Understand mathematical and scientific equations;
8. Have an understanding of various engineering fields;
9. Have experience with developing a portfolio; and
10. Possess basic computing skills.

Collectively, their study concluded that there are sixty-two essential engineering-related concepts that should be infused into technology education. These concepts are closely aligned with those presented in the *Standards for Technological Literacy, Engineering 2020*, and the *Accreditation Board for Engineering and Technology (ABET)* accreditation standards. Additional studies are currently being conducted within the technology education field to explore these as well as additional concepts. Thus, it is clear that a coherent conceptual base is developing that can inform engineering-oriented curriculum and course development at the K-12 level.

Recent Efforts at Infusing Engineering Content into the Technology Education Curriculum through Professional Development

The Centers for Learning and Teaching, programs funded by the National Science Foundation, have been focused on helping teachers improve mathematics instruction, science instruction, and improve in the applications of instructional technology. With the funding of the National Center for Engineering and Technology Education, the Centers now have a dedicated focus on providing professional development to teachers in order to help them infuse engineering design and other engineering content into the technology education curriculum.

Over the past decade, there have been a number of attempts to infuse engineering content into the technology education curriculum through professional development. A very significant set of projects have focused on the elementary school level. Some of these were funded by agencies

like the National Science Foundation and some were simply supported by technology education teacher organizations. Some efforts at the middle school and high school level have used professional development to help teachers and teams of teachers integrate mathematics and science (and other subject area content) into the technology education curriculum.

Some very noteworthy projects at the elementary level have followed a similar model, and some even focus specifically on engineering. Benenson and Piggott¹⁸ describe the City Technology Project that provides teachers with professional development in order to help them use design as a way of integrating the elementary school curriculum and emphasizing technology. City Technology emphasizes that students should collaborate in the design process and that design activities should focus on everyday objects in order to influence students more profoundly.

Another excellent example of integrating engineering into the elementary school through professional development is Children Designing and Engineering. Each summer, teams of teachers came together to learn how to integrate engineering design into the elementary school curriculum, develop instructional units, and finally field test the curricula. Teachers actually experienced the design problems and implemented them in the classroom. One of the guiding principles of this project is that the knowledge needed to solve the problem at hand is what teachers will help students learn. Teachers are not encouraged to stick to a traditional, rigid curriculum schedule.¹⁹

At the middle school level, the Technology, Science, Mathematics (TSM) Integration Project provided professional development to teams of technology education, science, and mathematics teachers who agreed to field test curriculum integration materials written by the project. The TSM focus is on students deliberately applying mathematics and science to the design and testing of technological solutions to problems. A key focus of the TSM approach is that the interdisciplinary team of teachers correlate instruction so that the science and mathematics is taught at the time that technology students need it for solving problems in the technology education lab or for analyzing solutions.²⁰ TSM uses a simple learning cycle which has students design, construct, test, and redesign. During field testing, students were able to see connections across the subjects and be more motivated to learn mathematics and science. However, it was difficult to find teams of teachers willing to work so closely together and who have common planning times, among other constraints to curriculum correlation.

Satchwell and Loepf²¹ describe the IMaST Project, which developed curriculum materials that integrate middle school mathematics, science, and technology (among other subjects). The IMaST curriculum was developed by teams of master STEM teachers who came together in the summer for training. Like the TSM Project, IMaST has a learning cycle associated with it: design, assess, plan, implement, and communicate. Both the TSM and IMaST projects focus on addressing national standards in mathematics, science, and technology.

Frye²² documented the engineering problem-solving process used in the Dartmouth Project. This project was an effort to get mathematics and science teachers to integrate engineering design into the high school curriculum. Later, technology education teachers were included in the professional development offered at Dartmouth. The focus was on helping teachers understand

how the engineering design process could motivate students to learn mathematics and science in more meaningful ways.²³

Rockland, Kimmel, and Bloom²⁴ describe a project called “Engineering the Future Enhancement of Pre-Engineering Program Through Outreach” also known as PrE-IOP, in which curriculum designed to infuse engineering concepts were developed to create connections between mathematics and science used in engineering applications in science and the workplace. Workshops were offered during the academic year along with summer institutes that were designed to familiarize the teachers with the curriculum and pedagogy. This professional development also included discussions and activities illustrating what engineers are and what they do. Practicing engineers and engineering students were used as role models.

Fontenot and Chandler²⁵ describe a pre-college engineering/architecture academy program for K-12. Texas Tech University College of Engineering collaborated with teachers to provide hands-on learning experiences. The teachers were trained to infuse engineering concepts with the core subject areas such as Language Arts, Mathematics, Science and Social Sciences. Teachers were encouraged to have students conduct research, develop writing assignments, progress reports, oral presentations, etc that correlate to engineering. Their projects could be about content areas such as robotics or rocketry.

At the middle school level, Project Lead the Way (PLTW) provides professional development to teachers of programs who agree to implement the PLTW curriculum. Rogers²⁶ describes the training as two week professional workshops in which experienced PLTW teachers and engineering faculty from each engineering area team-teach the teachers to effectively teach engineering content and concepts.

Also, the National Science Foundation has recently funded a project “Pre-College Engineering for Teachers” (PCET)²⁷, that provides K-12 teachers with a two week summer workshop along with academic year workshops to introduce teachers to various strategies for infusing engineering design into their classrooms. Each participating teacher is required to include at least one unit about engineering design into their classrooms during the following academic year.

Among all of the projects similar to those described already (including those associated with the ASEE), perhaps the most clearly relevant project that preceded the NCETE is the Bridges for Engineering Education project at the University of Georgia.²⁸ This NSF sponsored project invited teams of STEM teacher educators, engineering educators, public school science, mathematics, and technology education teachers, graduate students, undergraduate students, and high school students to participate in summer workshops that taught (among other things) teachers how to infuse engineering design into the technology education curriculum. The project used engineering design challenges in order to lead teachers into experiencing the engineering process, the application of mathematics and science in order to optimize solutions, predict their behavior, and analyze solutions, and to reflect on their learning and the implementation process.

The Bridges for Engineering Education professional development was highly rated by participants as useful and beneficial. It is interesting to note that three of the most important things learned by the public school students who participated were:

1. Engineering is a very intellectually demanding process.
2. Teamwork is very important in order to succeed at engineering design.
3. Becoming an engineer demands dedication.

Among the highest rated (mean = 4 for very useful) parts of the Bridges workshops and professional development were:

- What engineers do
- Steps in the design process
- Tours of engineering design firms
- Students' perspective on engineering
- Communication skills in engineering
- Engineering sciences
- Engineering laboratory exercises
- Engineering design results
- Women in engineering
- International design.

Among the most low rated (mean = 3 for useful; not very low at all) workshop components are:

- Principles of statics
- Design process in industry
- Principles of kinematics, dynamics
- Gears and mechanisms laboratory
- Electronics and sensors
- Circuit lab.

The Bridges project succeeded in getting the technology education teachers to infuse engineering concepts and design into their curricula. Mathematics and science teachers have also implemented some of what they learned. However, their main concern with full implementation is the amount of time that it takes from the standard mathematics and science curricula. Generally, participants wanted more laboratory time and fewer lectures, and it is clear that hands-on engineering design experience was the preference of most participants. Participants wanted more interaction time and time to discuss important and creative engineering ideas.

Across all of these projects and others, findings were similar. Local constraints to implementation have to be addressed and situating the professional development content in a local context is important to teachers' perceptions that they will be able to implement what they learned. Teachers are also more interested in the professional development activities when they see direct links with their existing curricula. These are fundamentals in adult learning theory.

In almost every case, teachers are fully involved in the STEM and problem-solving processes that are targeted to be implemented in the schools. The focus is on process rather than on memorization. The real-life, hands-on, context provides authenticity, relevancy, and motivation to learn. Teachers are helped to reflect on what they are learning, the profound and fundamental understandings, and how what was learned could be implemented. Professional development takes place over the course of a year instead of just a couple of weeks in the summer. Often

projects succeeded because of institutional buy-in by local participants' supervisors, principals, and school systems involved in the process. Austin and Koch²⁹, Burghardt and Hacker³⁰, and Shen, Gibbons, Wieggers, and McMahon³¹, describe additional projects with similar results.

The National Center for Engineering and Technology Education (NCETE)

The National Center for Engineering and Technology (NCETE)³, funded by the National Science Foundation, has engaged in an ambitious scope of work designed to infuse engineering concepts into the study of technology education. The Center is made up of four land-grant universities (Utah State University, University of Georgia, University of Illinois, and University of Minnesota) and five technology teacher education institutions (Brigham Young University, California State University – Los Angeles, Illinois State University, North Carolina A&T State University, and University of Wisconsin-Stout). The Center also includes three professional partners (the International Technology Education Association, the Council on Technology Teacher Education, and the American Society for Engineering Education). One of the most important partners of the Center, however, is the K-12 school district partners and teachers from around the United States. The core activities of the Center include professional development experiences for technology teachers, revitalization and reconfiguration of pre-service technology teacher education programs, the development of a cadre of graduate students (doctoral and masters level), and an ambitious program of research. The overall goal of NCETE is to strengthen the nation's capacity to infuse engineering into technology education at the K-12 grade levels. The goal, by 2009, will be to have developed a community of researchers and an associated body of research, to have prepared Bachelor and Master's level teachers, and to have increased diversity among students.

One central activity of the Center during its initial two years of existence has been to systematically identify and explore key differences between the content and culture of engineering and technology education. In collaboration with engineering partners at the nine universities that comprise the Center, it has become clear that considerable similarities exist between how engineers and technology educators conceptualize and implement design. Both academic disciplines identify and clarify problems, develop a range of possible solutions, select and prototype designs, and refine and develop designs for public distribution. In spite of these similarities, at least one key distinction exists. In various ways, engineering academic and professional culture employ a variety of analytical tools to predict the outcomes of specific design solutions relative to sets of engineering design specifications or constraints. For example, technology educators and engineers have both focused on the development and use of robotics. For both, this has included a range of topics such as configuration types, drive and power systems, end effector design (device or tool connected to the end of a robot arm), programming and more. The distinctive aspect of engineering is the ability to use specific mathematical and analytical tools (i.e., kinematics, linear equations, calculus functions, etc.) to plan and predict robotic arm movements prior to the implementation of designs. Whereas technology educators tend to base design on practical experience with tools and machines, engineers draw on a set of analytical tools.

While the design elements of technology education and engineering are substantially aligned in many respects, the predictive/analytical dimension represents a significant point of distinction.

The Center is actively exploring ways to enhance engineering prediction and analysis within technology education. The implications are serious and include the challenge of enhancing the science and mathematics capabilities of technology teachers, reconfiguring technology teacher education pre-service programs, and designing more analytically-based curriculum materials. Substantial progress has been made in NCETE center during the two years of operation, which include:

- a) The development of a set of engineering design challenges by teams of technology educators and engineers. The goal of this activity was to develop design activities that exemplify the use of mathematics and scientific tools for analytical prediction;
- b) Research designed to identify essential elements of engineering that are appropriate for delivery at the 9-12 level;
- c) Reconfiguration of pre-service technology teacher education programs to include increased mathematics and science requirements, and courses such as Engineering Design and Technology Education; and
- d) A book proposal to be authored by Center partners focusing on selected engineering and technology education topics.

The “Engineering Design Challenges” (first point in the previous list) represent an initial attempt to develop activities that are (a) consistent with core engineering concepts and (b) appropriate for 9-12 technology education. Each challenge represents a collaboration between the Center’s engineering and technology education partners. Each design challenge contains the following elements:

- a) a contextual scenario that is centered around an authentic technological issue or problem;
- b) specified goals and outcomes for student learning;
- c) discussion of the constraints that the engineering solution must adhere to;
- d) the social/cultural context of the issue;
- e) general classroom guidelines for the students and teachers to follow;
- f) the key engineering concepts that need to be delivered;
- g) educational standards and benchmarks;
- h) key mathematical and scientific skills/concepts that need to be incorporated into the activity; and
- i) an assessment tool for the students and teacher.

The culmination of the challenge (particularly for professional development purposes) is a reflective analysis section. In this section, students and teachers engage in a reflective analysis and debriefing session where they respond to a series of higher-ordered questions focused on the extent to which the challenge successfully delivered on its specified goals.

NCETE Professional Development

Ongoing professional development is being conducted at the technology teacher education partner institutions:

- Brigham Young University
- Illinois State University
- North Carolina A&T State University
- University of Wisconsin, Stout.

In addition to those described above, there are other distinct aspects of the NCETE professional development design that relate to lessons learned by past projects related to engineering and technology education. Generally, the following model by Loucks-Horsley, Love, Stiles, Mundry, and Hewson³², provides the basic design of the professional development component for the Center. Their model is a simple system, which proceeds as follows.

1. Commit to a vision and to a set of standards
2. Analyze participant and student learning and other data
3. Set professional development goals
4. Plan how to address those goals
5. Conduct professional development
6. Evaluate
7. Evaluation feeds back to redesign all aspects of the professional development design.

Partner school systems had to have a high percentage of reduced and free lunch students and the NCETE had to have letters of support from these school system partners in order to get funding. This prearranged support turned out to be a great catalyst for getting in-service technology teachers to participate in the professional development. NCETE professional development at each partner institution extends for 100 hours or more and is supported by school system supervisors and principals. Some of the 100 hours is conducted in the academic year and the rest conducted during the summer. As stated above, the emphasis is on engineering design, those things that are unique to engineering design, and contexts that are preexisting in the technology education curriculum. Attention is paid to challenges appealing to both genders and various ethnicities and races. A great amount of professional development time is spent applying engineering design and reflecting on that process and what was learned. A great proportion of time is also spent reflecting on how to implement what was learned in the teachers' laboratories and reflecting on issues related to implementation. Some partner institutions are now in a position to include pre-service teachers and mathematics and science teachers in the professional development activities in the second or third year. Along with NCETE senior personnel, Ph.D. fellows are being encouraged to study the effects of professional development in the public school technology education laboratory. Formative evaluation (face-to-face) is conducted during discussions and confidentially after each professional development session. Formative evaluation is also conducted at fall follow-up meetings and with participant portfolios. Summative evaluation is then conducted at the conclusion of the 100 hours in the summer.

Conclusion

In the November 2004 American Society of Engineering Education manuscript "Engineering in the K-12 Classroom"³³, John Brighton observed "No one should have to wait until after high school to be exposed to engineering". Furthermore, as part of Brighton's manuscript, the authors presented the results of research study focused on the attitudes of engineering at the K-12 grade levels. The conclusion was that over 80% of high school teachers believe that exposing students to engineering concepts is a crucial component of a well-rounded education. The respondents of this study, however, were quick to assert that teacher preparation and professional development are the keys to successfully implementing engineering concepts at the high school level.

Infusing engineering concepts into the K-12 grade levels will not be an easy task. Through the initial work of a myriad of people and professional organizations, a foundation is being developed to infuse engineering concepts into the K-12 technology education classroom. Further studies and work by the National Center for Engineering and Technology Education, the ASEE and other agencies and organizations must continue to contribute to this important effort. A close collaboration between the technology education and engineering communities has the potential for contributing substantially to the technological education of our citizenry as well as the security of the United States.

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