# AC 2007-1671: THE NATIONAL CENTER FOR ENGINEERING AND TECHNOLOGY EDUCATION: SUPPORTING TEACHER PROFESSIONAL DEVELOPMENT

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# The National Center for Engineering and Technology Education: Supporting Teacher Professional Development

## Introduction

William Wulf [1], president of the National Academy of Engineering, noted in his summary remarks at the IEEE Engineering and Education Deans' Summit Conference I, that encouraging engineers and educators to work together to address issues of technological literacy is a brilliant idea. The dialog between engineering educators and technology educators shows great potential for a symbiotic alliance to benefit both. The dialog has been facilitated by the publication of the *Standards for Technological Literacy,* [2] national content standards for technology education similar to, and aligned with, the national standards for mathematics education and for science education. The Standards for Technological Literacy (STL) were developed by the International Technology Education Association (ITEA) with funding from NSF and NASA. The STL were reviewed and endorsed by the National Academy of Engineering (NAE) and William Wulf wrote the forward to the document [3].

Salinger described the breadth of standards for science, technology, engineering, and mathematics (STEM) education and concluded that standards should promote cross-curricular teaching and learning and that the standards should be geared toward higher levels of achievement. He is not specific regarding what to teach, however, he strongly emphasized the need for curriculum integration among STEM subject areas.

The collaboration between engineering and technology educators is an important initiative that has tremendous potential for benefiting both. Therefore, the National Center for Engineering and Technology Education (NCETE) has been established.

## Goals and Purpose

The ultimate goal of NCETE is to build understanding of the learning and teaching problems encountered by high school students and teachers as they apply engineering design processes to technological problems. The engineering design process plays a central role in bringing about improvements in products and processes. Technology is central to the realization of processes and products. Both engineering design and technology are critical to the improvement of the quality of life. Taken together, engineering and technology are critical components of general education for all students as well as an orientation to a wide range of career opportunities.

The joining of engineering and technology education is being accomplished by teaming engineering faculty and technology educators to build capacity and infrastructure including collaborative technology teacher pre-service and professional development, funding for doctoral studies, and research.

*Perspective: The Relationship Between Engineering and Technology Education*

Introducing K-12 students to engineering concepts occurs formally in mathematics classes, science classes and technology classes, and informally through experiences in places such as science museums and discovery centers. NCETE emphasizes introducing engineering design and analysis formally through standards-based instruction in technology classes. One question that should be addressed is: Why did NCETE choose to introduce engineering concepts in technology classes? Why not work with K-12 science or mathematics teachers? The answer most simply stated is that design taught in technology education in K-12 is most closely related to engineering design. NCETE investigators think exposing K-12 students to engineering design will excite young people about the engineering profession. Furthermore, technology education exposes students to open-ended problem solving, a skill required of future engineers.

With the publication of the Standards for Technological Literacy [2], reshaping the technology education curriculum provides an important opportunity for engineering and technology education collaboration. The standards prescribe design concepts be introduced throughout the K-12 curriculum. Four of the 20 standards for technological literacy specifically address design: standard 8 deals with the "attributes of design," standard 9 with "engineering design," standard 10 with "troubleshooting, research and development, invention and innovation, and experimentation in problem solving," and standard 11 with "applying the design process." In the forward to the standards, William Wulf noted, "It is not enough that the standards are published. To have an impact, they must influence what happens in every K-12 classroom in America."

Technology education shares engineering education's desire to emphasize open-ended problem solving and the design process. For example, Standard 8 delineates design steps very similar to those introduced to engineering students. In order to recognize the attributes of design, students in grades 9-12 should learn that the design process includes:

- defining a problem,
- brainstorming, researching and generating ideas,
- identifying criteria and specifying constraints,
- exploring possibilities,
- selecting an approach,
- developing a design proposal,
- making a model or prototype,
- testing and evaluating the design using specifications,
- refining the design,
- creating or making it,
- and communicating processes and results.

The design process described by Standard 8 is iterative in nature so that students may make a number of models or prototypes that are tested and refined until the final solution is achieved. One difference between the design process prescribed by Standard 8 and engineering design is the role of engineering analysis in achieving the optimum solution.

Technology education is often misunderstood – it has undergone a significant transformation since the mid-1980's. At the core of this transformation is a transition from education associated with the industrial arts to education associated with technological literacy and engineering education in K-12 schools. This transformation is hardly complete, in part, because of stereotypical attitudes held by many. Greg Pearson [4], a Program Officer with the National Academy of Engineering, candidly points to some of the problem, "Let's face it, engineering is filled with elitists and technology education is for blue-collar academic washouts." In the same article, he recommends, "Leaders and influential thinkers in both professions have to decide that the benefits of collaboration outweigh the risks."

Establishing effective connections between the technology education and the engineering community, and overcoming the risks, is a slow process. One of the success stories in developing effective connections between the technology education and engineering communities was the development of the Massachusetts curriculum framework in science and technology/engineering. The Science and Technology/Engineering framework derives from two reform initiatives in Massachusetts: the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). Since 1992, the PALMS Statewide Systemic Initiative has been funded by the National Science Foundation in partnership with the state and the Noyce Foundation. The initial science and technology framework was approved in 1995 and was implemented in the field at the high school level. Groups of technology/engineering educators contributed to the development of a comprehensive set of standards and core standards for the technology/engineering courses at the high school level. The 2001 framework articulated standards for full-year high school courses in Earth and space science, biology, chemistry, introductory physics, and technology/engineering, making an effective connection between technology education and engineering. [5]

The 2006 revised Massachusetts science and technology/engineering curriculum framework calls for the highest quality pre-engineering high school courses. High school courses in which students should be provided opportunities for hands-on experiences to design, build, test and evaluate (and redesign, if necessary) a prototype or model of their solution to a problem. Students should have access to materials, hand and/or power tools, and resources needed to engage in these tasks. Students might also engage in design challenges that provide constraints and specifications students must consider as they develop a solution. [6]

*A Model for Technology Education*

A major proponent of including technology education in the framework was Ioannis Mialouis, former Dean of Engineering at Tuffs University and current president of the Boston Museum of Science. In 1997, after visiting a science classroom, he observed a curriculum that contained much about flowers and rocks and nothing about the science of everyday things such as planes and power plants. As a result, in that same year, Miaoulis started a statewide campaign to introduce engineering concepts into schools, making him a passionate advocate for technological literacy.

In 1998, Mialouis was appointed to the commissioner's panel that revised the Massachusetts state's standards, and saw the opportunity to improve the state curriculum. He reached out to the state's association of technology education teachers, many of whom had been losing jobs as schools closed down construction and automotive shops to fund computer labs. Miaoulis indicated that going to science teachers did not seem like a good idea because teachers that are secure in their positions would not see a need to change. "If I partner with technology education teachers, and make the case that adding engineering could upgrade their whole profession, and save their jobs, I would have the backing of that entire community." [7]

It did not go smoothly, as many technology education teachers without engineering degrees worried that they would be left behind. Others thought that science teachers would be asked to carry the load because of the strong math and science foundation needed. State officials did try to throw technology out of the standards, arguing that shop skills such as metalworking and woodworking did not belong in higher level academic standards. Miaoulis convinced them that technology education would become as academically relevant as physics when blended with engineering. David Driscoll, Massachusetts education commissioner, said "He showed a lot of political savvy during the process. He made a connection with people--from the governor to state education officials--and he was relentless in a nice way. He sold engineering to us in a way that demystified it and made a compelling case for teaching it to kids from an early age." [7] As a result, technology education personnel participated in the development of the framework.

*Technical difficulties*

Though the documented successes with pre-college engineering in Massachusetts have been lobbied to hundreds of politicians and school administrators throughout the country, no state has yet followed Massachusetts lead. Even within the state, most middle and high schools have been hard-pressed to implement the new standards. One hurdle is the lack of clear guidelines in the standards and the absence of curricular materials for the middle school grades. James Surowski said "In the 185 days available during our school year, an eighth grade science teacher already has to cover the Earth's history, change in ecosystems over time, the Earth and the solar system; … the list goes on. We can not hire a specialty engineering teacher--must make time for technology topics as well." [7]

## Method

One goal of NCETE is to find ways to teach engineering analysis as part of the 9-12 design experience. As the Center develops connections between the engineering and technology education communities, success with teaching engineering design at the high school level can effectively be achieved.

*NCETE Partners*

NCETE is a collaborative partnership between universities and school districts in regional teams located in the West, the Upper Midwest, the Central Midwest, and the Southeast. Regional teams engage in collaborative research, professional development, capacity building, and dissemination of research findings and model practices.

NCETE also facilitates collaboration between teacher education programs and 9-12 partners to build capacity and to share effective strategies and practices. Center partners have strengths in engineering and in technology education. Four categories of partners have been identified: 1) PhD granting university partners, 2) technology teacher education partners, 3) school district partners, and 4) professional society partners. A list of the NCETE partners is included in Table I.

Table I
**NCETE Partners**

| | |
|---|---|
| **<u>PhD Granting Partners</u>**<br>• Utah State University<br>• University of Georgia<br>• University of Illinois<br>• University of Minnesota | **<u>Technology Teacher Education Partners</u>**<br>• Brigham Young University<br>• California State University, LA<br>• Illinois State University<br>• North Carolina A&T State University<br>• University of Wisconsin-Stout |
| **<u>School District Partners</u>**<br>• Teacher education partners team with school districts in their geographical area | **<u>Professional Society Partners</u>**<br>• International Technology Education Association<br>• Council on Technology Teacher Education<br>• American Society for Engineering Education |

*Partner Collaboration*

NCETE is also organized for collaboration among the various levels of partners. The four doctoral university partners link and collaborate in strengthening PhD programs, developing four common core courses for PhD programs, developing effective recruitment strategies to ensure that a high quality, diverse cohort of PhD students is admitted to NCETE sponsored PhD programs, and developing a community of scholars among faculty and PhD students. The five teacher education partners collaborate by refocusing TTE programs, sharing effective recruitment strategies to attract a diverse student body, and sharing effective strategies to infuse engineering into technology education programs. The 9-12 partners link and collaborate by sharing best practices in terms of infusing engineering into the 9-12 schools.

## Mode of Inquiry

One key goal of the Center is to facilitate student learning relative to core engineering principles, concepts, and ideas. This is completed by delivering research-based professional development to technology teachers in the partner 9-12 schools.

A number of components have been utilized to facilitate this goal, including a series of teacher professional development experiences and, research designed to identify core engineering concepts, Design Challenge development, engagement with faculty from the STEM disciplines, and involvement of technology education pre-service teachers. An important emphasis of the professional development component of the Center is assessment-driven, open-ended problem solving applied to engineering design utilizing mathematics and science concepts.

The main objective of the professional development is to prepare technology teachers to incorporate engineering concepts into classroom and laboratory activities. By implementing a concentrated series of professional development experiences, NCETE faculty and graduate students use a set of activity-based engineering design challenges, intensive discussion, field trips and other activities to prepare teachers to incorporate engineering concepts into their courses. The technology education teachers assume two distinct roles during the professional development: 1) learning as students would learn, and 2) developing the knowledge and skills needed to deliver engineering-oriented technology education.

*Professional Development Issues*

Professional development is needed because the implementation of curriculum change toward the inclusion of engineering design into technology education depends primarily upon the current cadre of practicing teachers. While it is also desirable to infuse engineering design experiences into undergraduate programs preparing teachers, several years must elapse before a significant portion of teachers will have the new pre-service preparation. In an era of rapidly increasing technological change, a continuous process for professional development becomes imperative.

The potential audience for professional development includes current technology education teachers, both experienced teachers and recent graduates of teacher education programs. In addition, professional development targets specific audiences, such as engineers interested in making a career change to teaching and current teachers of other subjects, particularly mathematics and science, interested in teaching engineering and technology education.

Ross and Bayles [8] pointed out significant challenges in preparing teachers to introduce engineering design challenges:

- Teachers lack fundamental skills.
- Implementation is often abbreviated in the rush to build something.
- Few teachers explicitly discuss design challenges with students in the context of the scientific and mathematical concepts.
- Teachers are weak in the integration of concepts from science and mathematics.
- Few opportunities for engineering faculty members to provide professional development to substantial numbers of teachers.
- Most economical long-term solutions require improved pre-service preparation for teachers, probably using an interdisciplinary approach.

As a first step toward establishing best practices for delivering engineering design and content through professional development, engineers and technology teacher educators from each of the technology teacher education (TTE) partner institutions conceptualized, developed, and delivered a series of workshops. While the format and specific content varied across the five professional development sites, a balance between theoretical content and activity-based experiences has been maintained. At the conclusion of each workshop, participating high school teachers completed similar surveys, which were designed to facilitate analysis and reflection. Building on lessons learned during the initial year of the Center (2005), the TTE institutions moved toward a more common professional development experience during year two of the project (2006).

*Findings*

Looking at: 1) the Center's professional development outcomes of the first two years, 2) current professional development literature in math and science, and 3) input from the field of engineering, sheds light on an effective professional development model for engineering and technology education.

*1. Outcomes of the first two years.* As a result of the professional development workshops over the first two years, curriculum change is beginning to occur at the high school level. Across all sites, the participants indicated the professional development activities have "greatly increased" (44 %) or "increased" (49%) their ability to infuse engineering concepts into their teaching. The majority of participants (67%) indicated they will "definitely" begin their lessons discussing engineering concepts with their students and 27% indicated they would "probably" begin their lessons with this discussion. Many participants have already begun to incorporate engineering concepts into their curriculum (38%) or plan to do so (50%).

Rod Custer [9], PI for the NCETE TTE institutions, observed that for participants in the workshops, "the engineering design challenges clearly shifted the focus from trial and error problem solving to a more predictive process using mathematics and science tools. This is new to technology education and is an important key to aligning the profession more closely with engineering."

*2. Current professional development literature.* Based on the math and science professional development literature, and model practices used in professional development, a model for professional development can be adapted for technology education. Although the research base in math and science is less than definitive [10] [11], there is broad agreement in the field regarding several characteristics that are critical to the effectiveness of professional development initiatives [12]. The list of characteristics is comprised from the principles of effective mathematics and science professional development compiled by the National Institute for Science Education [13], professional development standards outlined by the National Council of Teachers of Mathematics [14], the National Staff Development Council [15], and the National Research Council [16]. Seven principles include:

- reflect a vision for the classroom based on research on how people learn and the nature of science and mathematics

- provide opportunities for teachers to build their content and pedagogical content knowledge and skills and to examine their practice critically
- research-based and use methods that mirror those used in the classroom
- provide opportunities for teachers to work with colleagues and other experts in professional learning communities to improve their
- practice support teacher leadership
- provide links to other parts of the education system
- based on student learning needs and are continuously evaluated to measure impact on teacher effectiveness, student learning, and/or the school community

An article in Prism Online [17] discussed that the key to success is the relationship with the teachers. Mrtha Cyr, a leader in the creation of the new engineering framework standards in Massachusetts said that "the greatest percentage of our work is in direct support of the teachers, who can be intimidated by the prospect of teaching engineering material." Professional development helps, Cyr says, but "much of it depends on the approach you use with the teacher. It's that interpersonal communication helping them understand how they can do this material in their classroom." Experienced teachers who know both their content and effective instructional strategies tend to produce higher achievement outcomes among their students [17].

Ross and Bayles [8] recommended that professional development activities should be:
- Local
- Sustainable
- Specific to the discipline
- Focused on specific content and skills
- Flexible
- Organized to provide on-going support
- Accessible for teachers with varying backgrounds.

Wilson [18] suggested that effective professional development:
- Focuses on student learning
- Focuses on content needed for teaching
- Incorporates teacher knowledge
- Is embedded in the work of teaching
- Employs collaboration
- Is a long-term endeavor

*3. Input from the field of engineering.* Recent developments in the field of technology education have resulted in efforts being made to understand the most effective methods available for implementing a curriculum that includes engineering content. In laying a foundation for this type of curriculum, it is necessary to firmly grasp the scope and nature of the engineering design process along with related subject matter from academic disciplines such as math and science. In a Delphi study conducted by Wichlein and others [19] experts were used to create a framework by which to understand how the engineering design process can be adequately explained and utilized in technology education classrooms to help students achieve technological literacy. Using data from practicing engineers and engineering educators in the study, there is a clear indication for a need for constraints, optimization, and predictive analysis (COPA) in the framework.

Douglas, Iverson, & Kalyandurg [20] in summarizing the results of an ASEE analysis of current practices in K-12 engineering education, developed the following guidelines for the future of K-12 engineering education. One, engineering education should be hands-on in order to motivate students by couching engineering problems in interesting and relevant social contexts. Two, engineering education should be taught in an interdisciplinary approach in order to show the relevancy of mathematics, science, and other subjects, by making engineering a conceptual place for the application of these subjects. Three, develop K-12 standards for use in lesson plans that help teachers teach mathematics and science concepts in the classroom. Douglas, Iverson, & Kalyandurg suggest that state-developed K-12 standards should be developed like Massachusetts has published. Four, improve teachers by providing more pay, more professional development, and more curriculum writing. Five, make engineering a more attractive career choice for girls and minorities by working with their schools through outreach efforts. Six, engage more constituents in partnerships that cross all levels of the educational process.

*Professional Development Model*

Over the last two years, as a result of participant feedback collected through surveys and informal communications, NCETE site coordinators have been making changes to their professional development efforts. The work of the first two years was evaluated to determine best practices of professional development. A research program associated with the design and delivery of the professional development is being developed and several of NCETE doctoral students are conducting research in this area. The goal is to develop an NCETE model of effective professional development to share with the technology education community. This model will be piloted during year three.

From the results of the research studies of current literature and a synthesis of the Center's first two years of professional development the following list should be included in a professional development model for engineering and technology education.

- Teachers involved in the professional development planning
- Teachers receive special recognition for being involved in professional development
- Based on theory, pedagogy, feedback and practice
- Focus on a small number of engineering outcomes.
- Include engineering design challenges

Currently student assessment is being studied to assess the impact of a set of carefully designed classroom interventions on student learning. These interventions will be based on a carefully selected set of engineering concepts and will be delivered using pedagogical content knowledge and best practices from engineering and technology education. Through the project, a cohort of practicing and pre-service technology teachers will design and develop a 20-day unit of instruction to deliver three core engineering concepts to secondary level technology education students. These core engineering concepts are constraints, optimization and predictive analysis (COPA). Prior to the development of the unit, all cohort teachers will have participated in professional development specifically focused on developing an in-depth understanding of the three concepts. This instruction is currently occurring as a key component of Illinois State University's NCETE TTE spring professional development workshops. Using a quasi-experimental, pre-test post-test design, the project will design and implement assessment procedures to explore the extent to which students understand the core engineering concepts. The study will consist of three phases including (a) designing the unit of instruction to deliver the core engineering concepts; (b) delivering the unit of instruction to secondary level students (grades 10-12); and (c) refining the unit for a second round of delivery and assessment. The unit will be designed during the NCETE TTE professional development workshop at Illinois State University and will involve technology education teachers from cohorts 1 and 2. In addition to technology teachers, the process will also involve selected teachers from mathematics and science, engineering, and doctoral fellows from the University of Illinois. Participating schools will consist of those schools at which the cohort teachers are employed. Students from intact classes will be invited to participate in the study. In phase 3 of the study, data collection will be expanded to include teachers and students from the 3rd year TTE professional development cohort. Descriptive and inferential statistics will be used to analyze the data. The primary focus of the analysis will be to assess the extent to which students' understanding of the three engineering concepts changes with instruction. These data will be collected using validated, parallel-form instruments (to minimize the treatment effect of the assessment process). Data analysis will also explore the relationship of prior mathematics and physical science instruction to engineering concept knowledge and performance gain. The findings will be disseminated through professional journals in engineering and technology education as well as through presentations at professional meetings [21].

At the time of the ASEE 2007 conference, a professional development model for technology teachers will be in the pilot stage. Evaluation survey instruments, designed by the Center's external evaluator in collaboration with the Center's leadership, will collect data from students and teachers to assess the extent to which the professional development model can contribute to effective engineering design for technology education. The professional development model and data will be presented at the conference.

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