2009

The Nature and Status of STEM Professional Development: Effective Practices for Secondary Level Engineering Education

Rodney L. Custer
Illinois State University

Jenny L. Daugherty
Illinois State University

Research

In

Engineering and Technology Education

ncete™

NATIONAL CENTER FOR ENGINEERING AND TECHNOLOGY EDUCATION

This material is based on work supported by the National Science Foundation Under Grant No. ESI-0426421

The Nature and Status of STEM Professional Development Effective Practices for Secondary Level Engineering Education

National Center for Engineering and Technology Education

Rodney L. Custer
Illinois State University

Jenny L. Daugherty
Illinois State University

Introduction

Recently engineering has emerged on the K-12 scene as a potentially important content area. However, K-12 teachers typically lack sufficient backgrounds to effectively integrate engineering into their classrooms. Thus teacher professional development is of critical importance. Although there have been several initiatives emerge to assist teachers in teaching engineering-related curriculum, there has been little empirical research generated. For example, little is known about best practices, engineering pedagogical content knowledge, or effective design principles for engineering professional development. Although there is a general consensus in the literature concerning a set of principles that differentiate effective teacher professional development (i.e., Garet, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003), little is known about how these translate to an engineering context. In addition, several complex issues have emerged that impact the implementation of engineering at the K-12 level, directly affecting teacher professional development.

The purpose of this paper is to report on the landscape study funded by the National Center for Engineering Education (NCETE) to examine engineering teacher professional development. This study evolved to include a synthesis of several activities and their outcomes with the intent to help inform future research and practice within NCETE. This report summarizes three major activities: (a) the *Professional Development for Engineering and Technology: A National Symposium* conducted February 2007, in Dallas, Texas (NSF funded); (b) a multiple case study of engineering professional development projects (Daugherty, 2008); and (NCETE funded as part of the Landscape study) (c) the *Symposium on Professional Development for Engineering and Technology Education: An Action Agenda* conducted June 2009, in Atlanta, Georgia (NSF funded). This report consists of two main sections: (a) a summary of the three major activities; and (b) a synthesis and discussion of the landscape of engineering-oriented professional development at the secondary level.

Background

The goal of the landscape study, as originally proposed, was to: (a) analyze current and past efforts to design and implement engineering-oriented professional development for 9-12 teachers and (b) identify best practices in professional development programs designed to prepare teachers for secondary level engineering programs. The study was to consist of a comprehensive review of the literature and case studies of selected professional development programs designed to prepare secondary teachers to deliver engineering-oriented technology education. As in most qualitative research, the focus of the study evolved and ultimately expanded to include a larger body of work engaged in by the researchers. In addition, the research questions driving this study evolved as the researchers engaged in the comprehensive literature review and the related activities. These research questions were:

1. What are the perceived critical professional development needs of teachers who are being prepared to incorporate engineering content and concepts into their teaching?
2. What are the best practices used to address the perceived professional development needs of teachers including techniques, pedagogical approaches, and strategies?
3. What is the fundamental content knowledge targeted by the professional development (e.g., pedagogical content knowledge, core engineering concepts, math/science principles)?
4. What are the pedagogical principles determined to be essential for the teachers?
5. What are the persistent and confounding challenges/barriers unique to engineering-oriented professional development?

The related activities engaged in by the researchers resulted in a comprehensive analysis of the issues surrounding engineering teacher professional development. Although the multiple case studies provide insight from the ground level, the two symposiums provided a broader context and framework within which to frame the overarching issues and research questions. Taken together, this body of work delivers on the proposal's original goal of developing a foundation of knowledge on which to ground future work in engineering-oriented professional development. This body of work is summarized below in the order each activity occurred.

Professional Development for Engineering and Technology: A National Symposium[1]

The goal of NSF-funded National Symposium was to explore a range of issues specific to engineering and technology education professional development. The event featured a set of nine refereed papers that were organized around three major themes including (a) core engineering concepts, (b) pedagogical content knowledge, and (c) effective professional development models. Following the Symposium, a number of activities were conducted to refine and synthesize the findings of the event. These included (a) extensive editing, refinement, and formatting of the refereed papers and focused small group discussions that were conducted in alignment with each of the major conference sessions, (b) the commissioning of three researchers with specialized expertise in STEM professional development to identify major themes/key issues/lessons learned focused on engineering and technology education professional development and (c) a meta-synthesis of the Symposium outcomes, identifying themes. The themes included:

- Theme 1 – Research Agenda: A programmatic research agenda should be formulated for engineering and technology education.

- Theme 2 – Clarify the Philosophical Focus: The philosophical focus of engineering across the K-12 levels needs to be established and articulated. *The Standards for*

[1] Professional Development for Engineering and Technology: A National Symposium. (February, 2007). *Proceedings and Future Agenda*, www.conferences.ilstu.edu/NSA/homepage.html. Dallas, TX.

Technological Literacy provide a framework that is broad in scope and designed to promote technological literacy for all students. An alternative approach could be to narrow the scope of the program to address the needs of pre-engineering students who are preparing to enter post-secondary engineering degree programs. There may be other alternatives along this spectrum.

- Theme 3 – Curriculum Development: Standards-based curriculum materials need to be identified and developed for use with engineering and technology education professional development. The lack of well-developed curricula is particularly problematic for professional development, which is best situated within the context of strong curricula rather than being based on a set of abstract principles and techniques.

- Theme 4 – STEM Collaboration: Mechanisms need to be developed to foster and enhance collaboration among the STEM disciplines. This collaboration should include curriculum, professional development, and research. While strong support is being voiced for STEM initiatives on a national scale, the focus of many (if not most) of these efforts continues to be directed toward the enhancement of mathematics and science rather than on collaboration, integration and mutual learning across all four areas. At the K-12 level, disciplinary boundaries persist across the STEM disciplines in terms of teacher preparation, professional development, curriculum, legislation, and funding. The challenges associated with promoting genuine STEM collaboration are non-trivial, systemic, and persistent.

- Theme 5 – Professional Development Models: There is a need to develop, pilot test, refine, and deploy professional development models for engineering and technology education.

- Theme 6 – Pedagogical Content Knowledge: Specific attention should be directed toward understanding the pedagogical content knowledge that is unique to engineering and technology education. The complex nature of engineering design, connections with mathematics and science content, and the diverse range of student and teacher backgrounds represent daunting pedagogical challenges that directly impact professional development.

- Theme 7 – Advocacy: Major work remains to be done to define and advocate engineering and technology education at the K-12 level. Among the factors that have generated this need are the historic lack of an engineering presence at the K-12 level, the general lack of recognition of technology education as a field of study by the general public and key educational stakeholders, and confusion of technology with computers. High quality professional development will continue to be profoundly problematic unless and until these perplexing definitional and contextual issues can be addressed.

***Engineering-Oriented Professional Development for Secondary Level Teachers: A Multiple Case Study Analysis*[2]**

The goal of this study was focused on the design decisions, engineering-specific content knowledge and pedagogies, unique challenges, and determinations of effectiveness by engineering professional development programs. The study consisted of multiple case studies of selected programs designed to prepare secondary teachers to deliver engineering-oriented education. This was achieved by exploring the professional development decisions and practices involved in five projects that incorporated engineering into their programs. The projects included in this study were *Engineering the Future: Science, Technology, and the Design Process™*, *Project Lead the Way™*, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*sm, and *INSPIRES*.

The research questions that guided the case studies of professional development focused on delivering engineering education evolved from the original proposal. Although elements of these questions are reflected, these research questions focused primarily on the design of the professional development experiences. The research questions were:

1. What are the primary design elements used to deliver engineering-oriented professional development (logistics, format, activities, instructors, and instructional strategies) and why were these elements selected?
2. What fundamental content knowledge is provided in the professional development (e.g., pedagogical content knowledge, core engineering concepts, mathematics/science principles)?
3. What pedagogical principles are determined to be essential for the teachers?
4. What are the particular challenges unique to professional development in engineering-oriented education?
5. How do the programs define and evaluate effectiveness?

A discriminate sampling technique, where the researcher deliberately selects persons, sites, and documents to maximize comparative analysis (Strauss & Corbin, 1998), was used to select the five cases for analysis. Based on the review of literature and research questions, the following criteria were developed to help guide the case study selection process.

1. *Engineering-Oriented Content*: The cases had to contain elements that were interesting, applicable, and useful for engineering-oriented professional development at the 9-12 (secondary school) level. Engineering was defined as including a focus on: (a) preparing students for postsecondary engineering education or (b) providing a broad base of technological literacy for all students. A focus on secondary school level projects was included because of the predominance of initiatives targeting this grade level.

2. *Illuminative Professional Development Design Practices*: The initiatives needed to have a reputation for attempting to include "best practices" (e.g., standards based, pedagogically sound, and assessment based), as well as creative design practices, that could illuminate and inform future professional development in this area.

---

[2] Daugherty, J. L. (2008). *Engineering-Oriented Professional Development for Secondary Level Teachers: A Multiple Case Study Analysis*. Dissertation, University of Illinois, Urbana-Champaign.

3. *Maturity*: Priority was given to mature initiatives with an established track record for delivering professional development over a sustained period of time (at least two years).

The data collection process for each case study was conducted by the project's PIs, Jenny Daugherty and Rodney Custer, and consisted of the following phases: (a) pre-visit, (b) on-site, and (c) post-visit. The pre-visit data collection phase consisted of two elements: (a) structured telephone interviews with the project's leaders, and (b) an analysis of the project's documents. The structured hour long telephone interviews with the project's leaders were conducted to collect factual data about the project to help provide the "back story" and inform the on-site data collection. The project leaders were also asked to supply evaluator reports, curriculum, and related documentation of the project. These documents were reviewed to better understand the project's development, philosophy, and approach to professional development. The data gathered from the interviews and documents were synthesized and developed into the foundation of the case study report prior to the on-site visit.

The on-site data collection was conducted over the span of two days. The rationale for conducting on-site visits was to (a) obtain first-hand reports from the projects' participants, (b) directly observe the professional development activities and interact with project leaders and participants, and (c) document and validate information obtained from the pre-site interviews. In order to ensure the triangulation of data, the on-site data collection for this study consisted of the following three methods: (a) observations conducted during the Summer of 2008, (b) teacher questionnaires, and (c) interviews (teacher focus groups, instructors, and project leadership).

The first on-site day consisted primarily of observations guided by an observation form. At the end of the first day, a survey questionnaire was also administered to all of the teachers. The same questionnaire was administered at all of the sites, providing data for comparison across the cases. On the second day, focus group interviews of the teachers, interviews with the professional development instructors, and follow-up interviews with the project leadership were conducted. Teachers were asked about what they were learning, how it would influence their teaching, and strengths and weaknesses of the experience. The interviews with the instructors were intended to provide information about the materials, the delivery of the instruction, and their training. By the end of the second day, if unanswered questions remained, informal interviews of the project's leadership occurred. All interviews were audio-recorded and transcribed by a professional transcriptionist. The background report prepared from the pre-visit data, the observation notes, and the analysis of the transcripts were compiled into case study write-ups.

During the post-visit data collection phase, member checking was conducted to ensure the accuracy of the case study write-ups. The project leaders were asked to examine their project's case study report and provide feedback on any inaccuracies related to the project's history and development. Inaccuracies were reconciled via a telephone conversation Based on the project leaders and review panels' feedback, full descriptive case studies were prepared for each case. The background report, the analysis of the transcripts, and a descriptive narrative of each on-site visit were integrated into separate case studies. This approach allowed the researchers to gain a rich familiarity with each case, resulting in the emergence of unique patterns within each case before pushing "to generalize patterns across cases" (Eisenhardt, 1989, p. 540). In addition, each of the case studies and an initial analysis of unique patterns across the cases were subjected to a thorough review by a panel of three engineering and technology education experts (Drs. Martha Cyr, Brian McAlister, and Ty Newell).

The five case studies are presented in an abbreviated form in the order they were visited. As Stake (2006) pointed out, what multiple case studies "have most to offer is a collection of situated case activities in a binding of larger research questions" (p. 90).

Engineering the Future: Science, Technology, and the Design Process™ (EtF)

The National Center for Technological Literacy (NCTL) at the Museum of Science, Boston began the EtF project to develop a full-year course designed for all students in their first years of high school. Professional development emerged from the field testing of the curriculum. Currently the professional development is comprised of two designs: (a) in-person workshops and (b) online courses. The in-person workshops are structured around a combination of mini-lectures, hands-on activities, and reflections. Each of the four days of the workshop observed for this case study was devoted to one of the four projects in the course. The instructor structures the professional development experience around the five E's (engage, explore, explain, elaborate, and evaluate). The evaluation included daily plus-delta activities and a summative feedback form. In addition, online courses enable the project to introduce, train, and support teachers using the curriculum nationally. EtF's professional development has reached over 160 teachers and 7,500 students in 16 states.

Based on the pre-visit interview with the project leadership and the on-site visit, it is clear that the EtF professional development is directly linked to the curriculum. The focus of the workshop was on exposing teachers to the curriculum through hands-on activities. Instruction on these activities was often guided, following a step-by-step process outlined in the curriculum. Practical implementation issues were often outlined including how best to obtain and store supplies, assess student learning, and access website resources. The content and pedagogical approaches identified in the professional development were also directly linked to the curriculum and the activities selected for the teachers to complete. The engineering design process was intended to provide the content base for the engineering aspect of the course and the professional development. And although specific pedagogical principles were not explicitly discussed, the instructor often pointed out how teachers could deliver the activities in their own classrooms.

Project Lead the Way™ (PLTW)

PLTW is an instructional project that is designed to prepare students to be successful in post secondary engineering and engineering technology. There are three elements of PLTW's professional development design: (a) self-assessment and pre-core training, (b) core training in the form of summer training institutes, and (c) continuous training. Teachers take a skills self-test and questionnaire to determine their readiness for core training in three basic areas: (a) mathematics, (b) science, and (c) computer literacy. The two week (80 hours) Summer Training Institutes (STIs) are conducted at an affiliate training center; typically a university. There are STIs for each of the PLTW's courses within the middle school (*Gateway to Technology*) and high school programs (*Pathway to Engineering*). Master teachers and affiliate university professors lead the STIs. The master teachers assist in developing the "scope and sequence" of the workshop that will be used at all STIs across the country. Continuous training is provided to the teachers in the form of university based level II training and a virtual academy.

Based on the pre-visit interview with a project leader and the on-site visit of the *Introduction to Engineering Design* (IED) STI, the content and pedagogical approaches were directly link to the curriculum, in particular to activities within the IED course. The content was focused on computer aided drafting. The hands-on activities progressed from a guided activity to draw an object (a train engine) to an open-ended design problem (design a train car to attach to the train engine). The overall approach appeared to be to scaffold design on top of specific tool use development. In other words, instruction was provided on specific tools using a demonstration/lecture technique, and then teachers moved on to more open-ended design projects after the "basics" were learned.

Mathematics Across the Middle School MST Curriculum Project (MSTP)

MSTP is a National Science Foundation Mathematics Science Partnership (MSP) project focused on teacher professional development. There have been three distinct phases of the MSTP project's approach to professional development. The first phase utilized a train-the-trainer approach. The second phase had teachers meeting twice (A workshop and B workshop) and between implementing a mathematics-infused lesson, bringing examples of student's work to the second workshop. The third phase, which was observed for this case study, was to result in an experimental control group research study designed to measure the impact of a mathematics-infused design lesson. The workshop, facilitated by a lead teacher and supported by a mathematics education expert, provided the teachers with the experience of working through the lesson, which also emphasized virtual and physical modeling.

The MSTP project's primary goals are to develop science and technology teachers' abilities to infuse mathematics into their teaching. Specifically with technology teachers, the project has used design as an approach to accomplish this goal. Developing an informed design process, where mathematics and other related content are infused as knowledge skill builders, provides a guide for teachers who do not necessarily have a mathematics background. The content and pedagogical approaches were directly linked to the goal of infusing mathematics into science and technology. The mathematics consultant sought to model how to build mathematics into a design-oriented technology lesson. In addition, the project sought to incorporate a "hybrid" modeling approach to the design lesson, preparing teachers to use an online computer aided drafting tool and physical modeling, and reflecting on the benefits of this approach.

The Infinity Project^{sm}

The Infinity Project^{sm} is a partnership between Southern Methodist University (SMU) and Texas Instruments that resulted in a year-long, upper level high school course titled *Engineering Our Digital Future*, and an adapted version for 9th and 10th grades. The instructional materials include a textbook, lab materials, an instructor's guide, and a technology kit utilizing LabVIEW software. Classroom support is provided through the project's professional development institutes, which are week long (40 hour) sessions hosted by SMU or other university partners. Institutes include hands-on instruction by master instructors in the use of the hardware, software, and textbook features of the curriculum. Open lab time is built into the format of the institute, which is structured around the textbook's chapters. The primary focus of the institute is on learning how to use the LabVIEW software. The evaluation component of the institute included a pre-test/post-test assessment. Teachers are asked to complete the assessment before they attend the institute and then at the end of the institute they are asked to complete it again.

Based on the pre-visit interview and the on-site visit, the instructional design of the institute modeled a typical post-secondary engineering education approach. The master instructor presented the broadly structured conceptual information without a lot of guided instruction on using the software. The teachers then worked through the labs at their own pace, where they developed more fully the use of the software and were able to apply the concepts. Although the teachers attending the workshop were comfortable with this approach, there were some particular challenges noted by the leadership. One of the challenges that the project leaders identified was the mathematics deficiencies in some of the teachers. One way that the project has sought to remedy this challenge is by requesting that teams attend the institute, with one of the teachers having a mathematics background. In addition, teachers are sent a memo prior to attending the institute outlining the mathematics concepts involved in the curriculum so they can review those that are less fresh in their minds. Another remediation undertaken by the project was to have one of the master instructors create a mathematics "refresher" for teachers online.

INSPIRES

INSPIRES is an NSF-funded project with the purpose of "Increasing Student Participation, Interest, and Recruitment in Engineering and Science." The *INSPIRES* curriculum targets core engineering skills and concepts in order to better prepare students to pursue engineering and technology related careers. At the time of the on-site visit for this case study, the *INSPIRES* project had completed three of its five stand-alone modules, which are centered on specific engineering design challenges. As they completed a module, the project's leaders conducted two-day teacher workshops. The observations conducted for this case study were completed at a workshop focused on the *Engineering Energy Solutions: A Renewable Energy System Case Study* module. The workshop consisted of an overview of the project and then experiencing the curriculum in the same order and format that it is to be implemented in the classroom. The teachers also work through the web-based tutorials and interactive simulations that are included in the module. The workshop begins and ends with an evaluation survey.

Curriculum dissemination and implementation are the primary goals of the *INSPIRES* professional development. The workshop is structured around: (a) PowerPoint presentations delivered in a lecture-style format, (b) self-guided online tutorials and assessments, and (c) hands-on design challenges and demonstrations. In addition, discussion and reflection were integrated throughout the workshop to regularly draw the teachers' attention back to classroom implementation. Based on the instructional strategies used in the workshop, the essential pedagogies to teach this module can be divided into three main approaches: (a) lecture to deliver content, (b) demonstrations, and (c) facilitation of self-guided online tutorials and hands-on design challenges.

Review Panel

A panel of three engineering and technology education experts was asked to read through the case study write-ups. Drs. Martha Cyr, Brian McAlister, and Ty Newell have experience working with engineering and technology education teacher professional development and bring important perspectives to research in this area. A teleconference was convened with the group to discuss and capture their reactions to the cases and analysis of patterns to help refine the thinking of the PIs on the project. In order to help guide the discussion, the following questions were posed to the review panel:

1. Do the case studies relay the important information to understand the projects?
2. What struck you as interesting/important to the study?
3. What consistent issues did you see emerge?

The review panel agreed that the case studies relayed the important information and that the major issues were captured. A variety of aspects struck the panelists as interesting and important to the study. For example, an issue that struck one panelist as interesting was the apparent assumption that good curriculum necessarily translates into good professional development. Those issues that they found to be consistent across the cases included the central role of curriculum, the lack of engineering content, a primary focus on activities, little reflection on pedagogy, and the importance placed on instructor credibility. A few issues that the panelists thought would have emerged more prominently in the cases but did not were accountability, institutional barriers to implementation, and teacher deficiencies in certain areas such as mathematics. In addition to the consistent issues, the panelists suggested that the PIs examine issues surrounding equity and diversity, as well as to examine any trends according to teachers' disciplinary backgrounds. The review panel discussion helped inform the summary of findings below, as well as greatly impacting the culminating activity.

Summary

The findings from the individual case studies were compared and summarized across the study's research questions. In addition, a cross-case search for patterns and issues within each case study's findings was conducted. Based on these patterns, conclusions were made concerning secondary level engineering-oriented professional development. These conclusions included:

- Professional development for secondary level engineering-oriented education predominantly uses a curriculum-linked training model. All of the projects but one began as formal curriculum development projects and the other centered its professional development program on the implementation of a particular lesson. The developers designed their programs around providing training on specific implementation skills.
- Two distinct philosophies guide secondary level engineering-oriented professional development: (a) technological literacy, and (b) pre-engineering. Although there were co-existing elements to the project's philosophies (mathematics infusion, technology focus, equity issues), these distinct philosophies guided the professional development program design and impacted how engineering was conceptualized.
- Engineering content is not well-defined for secondary level education. The projects' leaders, instructors, and teachers discussed engineering content in terms of an engineering design process with little elaboration on identified content, knowledge, or skills necessary to successfully implement. (NOTE: This conclusion contributed directly to the decision to pursue funding for research designed to identify engineering concepts for secondary level education. That project was funded by the National Center for Engineering and Technology Education and was completed in July 2009).
- The two instructional design approaches dominant are: (a) scaffolded problem solving and (b) self-guided learning. With the scaffolded problem solving approach, guided instruction on tool usage progressed into more open-ended design based activities. With the self-guided learning approach, broadly structured conceptual information was

presented with minimal instruction on tool use. The majority of time was devoted to the teachers self-directing their learning.

- Science, technology, and mathematics teachers have different professional development needs to incorporate engineering into their curriculum. With the diverse backgrounds in preparation and education of teachers in these three disciplines, there appears to be a variety of needs that require attention in a program that draws from these three areas.
- Active engagement in hands-on activities with minimal reflection on the learning processes involved is a consistent pattern in secondary level engineering-oriented professional development. The programs included in this study devoted most of their instructional time towards teacher engagement in hands-on activities.

Symposium on Professional Development for Engineering and Technology Education – An Action Agenda

After a careful synthesis of findings from the two activities described above, a second symposium was planned and conducted. The second symposium (held in June, 2009) was designed to develop, refine and validate research and practice agendas. The research questions guiding this project were:

1. How can the outcomes from the *Professional Development for Engineering and Technology: A National Symposium* (2007), the multiple case study research project (2008), and related research inform the development of a conceptual framework for engineering professional development research and practice?
2. What are the important research themes identified in the two activities, related research, and by STEM experts for engineering professional development at the secondary school level?
3. What are the recurring key issues that must be resolved for the development and practice of comprehensive and effective engineering professional development at the secondary school level?

The planning of the second symposium consisted of two main phases: (a) a synthesis and validation of the two primary activities and (b) a refinement and validation of research and practice agendas within a conceptual framework. An analysis of the outcomes of the two major activities (the first symposium and the multiple case study research project) resulted in a synthesis of key issues pertinent to secondary level engineering teacher professional development. The issues included:

1. Lack of Defined Engineering Content (concepts, processes, skills)
2. Pedagogical Culture Differences (education/scaffold learning and engineering/self-guided learning)
3. Different Philosophies of Secondary Engineering (technological literacy and pipeline)
4. Diverse Needs of MST Teachers (interrelationship among STEM disciplines)

This synthesis was subjected to a validation process that included a presentation to a panel of engineering and technology education experts. The expert panel's reactions and critiques were captured and used to further refine the framework. In addition to the validation of the framework, the panel was also asked to review and provide suggestions on a preliminary planning for the second research symposium. Based on their feedback, along with the research literature, the project's leadership developed a conceptual framework and draft agendas for research and practice to be refined during the second symposium.

The conceptual framework was developed to structure the development of the draft agendas. The framework was comprised of four primary dimensions including the Context of Secondary Engineering Education, the Processes of Secondary Engineering Education Professional Development, Secondary Engineering Content, and Outcomes of Engineering Education Professional Development. Three of these dimensions were based on the National Staff Development Council's (2001) design principle categories: (a) context, (b) process, and (c) content. A fourth dimension labeled outcomes was added. Based on the synthesis and extensive literature review, research questions and recommendations for practice were identified for each of the four dimensions to comprise draft research and practice agendas.

Twenty five participants attended the second symposium including representatives across the STEM disciplines, those with established expertise in mathematics and science professional development, Director level leadership from three national professional STEM Centers, and engineering-oriented curriculum developers. The format for the two days consisted of (a) presentations of three case studies focused on professional development (*Project Lead the Way*, *The Infinity Project*, and *INSPIRES*), (b) presentation of a conceptual framework and draft agendas for research and practice, and (c) an activity designed to validate and refine those agendas.

The draft agendas for research and practice were presented to the group and then the participants, in small groups, engaged in a comparative analysis of the results of their case study-based deliberations and the draft agenda items. These discussions were carefully recorded by previously identified note-takers, as well as the project leadership. The participants were asked to provide feedback on the agendas, as well as the conceptual framework. The small groups reported out to the entire group a summary of their discussions. This led into a whole group discussion. The feedback was captured by the note-takers and project leadership, which was used to refine the framework and agendas.

The symposium yielded specific feedback and proposed revisions to both the framework and to the research and practice items. Revisions to the framework included: (a) a separation of the research and practice agendas; (b) the addition of another category of inputs to the research agenda; (c) the creation of a different framework (categories) for the practice agenda; (d) general research themes instead of specific research questions; and (e) broad issues impacting the practice of professional development, instead of recommendations. The changes and additions to the research and practice items were based on the compiled list of consistent issues raised during the symposium. The revised agendas were sent to the symposium participants via email for another round of input. All that responded approved the revisions. The agendas are presented below.

Category	Research Themes
1. Context of Secondary Engineering Education	• The ideological climate of engineering education at the secondary level (technological literacy and pre-engineering) • Organizational structures/systems of secondary schools and professional development providers (i.e., universities, state education entities, curriculum developers) • Students, teachers, administrators, guidance counselors, parents, and community members' understandings, views, and attitudes of high school engineering education • Barriers to implementing engineering at the secondary level
2. Inputs to Secondary Engineering Education Professional Development	• Recruitment (teachers' motivations and incentives to participate) • Approaches for recruiting a diverse teacher population to participate (i.e., racially, ethnically, gender) • Teacher involvement and collaboration in design, delivery, and evaluation • Identification of prerequisite knowledge and skills for successful participation in PD • Effective pre-assessment and pre-training approaches • Designs of effective engineering professional development (i.e., additive and/or transformative models) • Depth and duration • Role of curriculum • Affective element – teachers' values, potential risks and rewards, readiness for change • Accessibility of engineering for all
3. Processes of Secondary Engineering Education Professional Development	• Strategies that facilitate the change process • Instructional approaches that effectively impact teachers learning engineering as adult learners and reflective practitioners • Disciplinary-specific differences in mathematics, science, and technology teachers' learning engineering • Learning communities (i.e., teams of teachers from the same school, virtual communities) • Teacher action research • Use of engineers in PD • Approaches to increase retention and implementation • Design, implementation, and impact of rigorous formative and summative evaluation
4. Secondary Engineering Content	• Content, pedagogical, pedagogical content, and subject matter knowledge related to engineering needed for teachers to teach engineering • Skills (pedagogical and technical) needed to implement engineering • A well-defined image of students learning engineering

	• Engineering learning progressions • Assessment (i.e., examples of students' work as an approach to assessing impact) • Transferability of PD learning to classroom practice
5. Outcomes of Secondary Engineering Education Professional Development	• Indicators of success • Sustainable teacher change (knowledge, pedagogical approaches, skills, beliefs, and attitudes) • Student learning • Teachers as leaders (within and outside schools) • Sustainability

Category	Practice Issues
6. Policy Issues	• The underrepresentation of Technology and Engineering in the K-12 should be addressed in curriculum, program and professional development planning and implementation. • The "siloed" culture of secondary education is a serious problem that needs to be confronted in order to integrate engineering content.
7. Access Issues	• Planning for engineering professional development should concentrated on preparing teachers to appeal to underrepresented groups, particularly women and minorities. • Engineering-oriented professional development should be designed to address the diverse needs of science, technology, and mathematics teachers.
8. Curricular Issues	• A set of standards-based outcomes should be developed to assess the quality of engineering-oriented teacher professional development. • Standards-based materials need to be identified, developed and disseminated for K-12 engineering education classroom instruction and professional development. • The design of secondary level engineering-oriented professional development should be comprehensive, extending beyond training designed to implement a specific set of curriculum materials. • Engineering professional development should focus on building teachers' understanding of significant concepts and avoid focusing only on design activities for their own sake.
9. Pedagogical Issues	• Engineering professional development should focus on causing teachers to reflect on their teaching, including the nature and quality of their pedagogy, the quality of the curriculum materials, student learning, and assessment. • Pedagogical content knowledge, unique to engineering content and skills needs to be identified and incorporated into professional development. • A variety of research-based, engineering-specific professional development models need

	to be developed, pilot tested, assessed, and refined.
10. Pre-service Issues	• Preparing to deliver engineering content in the public schools will require significant changes in how teachers are prepared at the pre-service level. Important issues include mathematics and science requirements, core engineering content, curriculum and activity development, unique pedagogical demands, and appropriate collaboration with other STEM teachers. • Decisions need to be made regarding where engineering content will be vested in the schools (e.g., technology education, science, mathematics, STEM). These decisions will impinge directly on pre-service engineering education. • Decisions should be made about the extent to which pre-service programs will engage with nationally-oriented professional development programs (e.g., PLTW, Infinity, etc.).
11. Reform Issues	• Planning for engineering at the K-12 level should occur within the larger context of school reform. • Research from the cognitive sciences should be incorporated into professional development planning, implementation, and research. A cognitive science focus is necessary to shift from a emphasis on activities to concepts. • Procedures need to be developed for assessing the ways and extent to which engineering-oriented professional development translates into student learning. • Engineering professional development programs should incorporate adult learning principles and effective professional development practices.
12. Advocacy Issues	• Planning should be directed toward educating and securing the support of key constituents including guidance counselors, administrators, and parents. • The resources of the National Academies, the NSF, and the professional associations of the various engineering disciplines should be deployed to clearly define and promote an identity and vision for engineering at the K-12 level. • Planning needs to be done to engage the broader engineering community in professional development planning and delivery. • Professional development planning should include strategies for scale up and sustainability.

Synthesis

The body of research represented by these three activities have resulted in the examination of some of the key issues across the landscape of engineering professional development at the secondary school level. Through the extensive review of the literature throughout this work, it is evident that there is relative consistency within the literature regarding what constitutes effective teacher professional development practice. Generally, professional designers need to consider a range of factors including the extensive knowledge base that can inform their work, unique contextual features, a wide range of professional development strategies, and critical education reform issues. Particularly evident is the importance of the larger contextual issues surrounding teachers' work and development. Teacher learning does not occur in a vacuum; rather it is woven into school culture, instructional mission, and organization, as well as teachers' knowledge and the learning and achievement of students. This complexity makes "it difficult, if not impossible, for researchers to come up with universal truths" (Guskey, 1995, p. 117).

Some consistent elements have emerged across the STEM professional development literature (Darling-Hammond & McLaughlin, 1995; Garet et al., 2001; Desimone, Porter, Garet, Yoon, & Birman, 2002; Loucks-Horsley et al., 2003). Effective professional development designs are those that:

- Are reform-oriented (grounded in inquiry, reflection, problem solving and experimentation),
- Engage all constituencies in collective and collaborative participation including students, teachers, parents, school officials, and even the wider community,
- Involve participants in active and in-depth learning opportunities,
- Are driven by a well-defined image of effective classroom learning and teaching,
- Are focused on improving teachers' knowledge of their content and how to teach it to students,
- Include mechanisms for continuously improvement and evaluation, and
- Are embedded within the larger school culture and context.

The extent to which these design elements have emerged in the activities outlined above is somewhat mixed. Strong points of alignment include the emphasis on active engagement, problem-solving, and experimentation as well as some clear notions of what constitutes effective learning and teaching. Less evident is an emphasis on content, reflection, and sensitivity to reform and school culture. The importance of these elements is evident in the research and practice agendas. Regardless, the larger body of STEM professional development literature is instructive and provides a broad framework within which to think about engineering-oriented professional development.

Based on a synthesis of the outcomes of these related activities, several important general observations can be made about engineering at the pre-collegiate level. While these observations emerged from projects focused on professional development, they involve a broader set of issues that tend to be more systemic and extend beyond professional development. It is also important to note that while the focus has been at the secondary level, many of these issues may also apply across the K-12 spectrum.

A particularly important issue that consistently emerged across the activities is the purpose of engineering at the secondary level. There are different ways to approach the inclusion of engineering into the high school classroom: (a) as an avenue to technological literacy, and (b) as a pathway to post-secondary engineering education. The focus on technological literacy situates pre-college engineering firmly within technology education. With two of the five groups of standards in the *Standards for Technological Literacy* (ITEA, 2000) focused on design, many have indicated that engineering fits within technology education (Lewis, 2005; Wicklein, 2006). The alternative, a pre-engineering approach, models engineering at the post-secondary level, with a strong emphasis on mathematics and science. These programs are designed to educate and excite students about future careers in engineering. Concerns have been raised however about approaching engineering at the secondary level as a pathway to post-secondary engineering in that only a select population of interested and capable students will benefit. These two distinct philosophies affect how engineering is approached at the secondary school level impacting the design of curriculum, instruction, teacher preparation and professional development.

In addition, the different approaches to engineering confuses where in the K-12 curriculum engineering is best housed. There is serious concern about where engineering content should be located and what it would replace in an already crowded curriculum. Should engineering become part of the existing science curriculum, with the associated benefits of engaging students in real world science and mathematics applications? Or should efforts instead be focused on retooling technology education classes to house engineering? The second approach, however, raises significant capacity and public perception issues. The technology education field lacks the large number of teachers that would be required to deliver engineering on a large scale basis. Further, many in the general public confuse design-oriented technology education with computers and other instructional technologies used in various ways throughout the schools.

A related issue connected to professional development is how to address the needs of teachers from several academic disciplines. Generally, these include mathematics, science, and technology education teachers. In some cases, teachers from other disciplines may be included as well. While this type of interdisciplinary collaboration is often quite positive, diverse backgrounds frequently pose difficulties for professional developers. Due to the differences in their pre-service teacher education, teachers' backgrounds and capabilities often vary across and within these three disciplines. In those cases, where professional development programs are designed to facilitate cross disciplinary teams, it is sometimes difficult to transplant the same level of collaboration back into real schools, with all of their scheduling, curricular, and assessment constraints. Professional development must then be flexible enough to meet diverse teacher needs, particularly as they relate to varying levels of science, technology, engineering, and mathematics abilities and comprehensive enough to impact all of the teachers to transfer their learning into their classroom practice; a tall order for professional development programs.

Incorporating engineering into the K-12 schools on a large scale will also challenge colleges of education and engineering to develop new models for teacher education. This will, of course, hinge on policy decisions, including the discipline(s) with which it is aligned. One model could be to restructure preservice science and technology education programs to focus on the delivery of engineering content. Another model could be for colleges of education to certify students with undergraduate engineering degrees to teach through programs delivered at the Master's Degree level. Regardless of the model used, preparing to deliver engineering content in the public schools will require significant changes in how teachers are prepared at the pre-service level. Important issues include mathematics and science requirements, core engineering content, curriculum and activity development, unique pedagogical demands, and appropriate collaboration with other STEM teachers. Decisions also need to be made about the extent to which pre-service programs will engage with nationally-oriented curriculum programs (e.g., *Project Lead the Way*, *The Infinity Project*, *Engineering byDesign*).

As these curricula reflect, secondary level engineering education tends to consist of a variety of engaging design activities. This is not surprising given the process-based nature of engineering design and the history of programs that typically house engineering at the pre-collegiate level. What is much less apparent, however, is the presence of a solid conceptual base for these activities and classroom experiences. For engineering professional development, this lack of emphasis on concepts and content differs from the strong emphasis placed on content in mathematics and science professional development. The question "What are students learning?" is an important one, particularly in an era of standards, high stakes assessment, and Federally-mandated accountability. The researches and a colleague (Joseph Meyer) have received funding from NCETE designed to identify and validate a set of core engineering concepts to help inform this conceptual base. But more work is required in this area if engineering is to be considered a viable subject at the K-12 level.

Lastly, a consistent finding across these activities examining engineering professional development at the secondary level is a general lack of reflection on pedagogy. The general tendency is for the teachers to concentrate on successfully completing design challenges that they can then take back to their classrooms. In many cases, the primary focus is on tools, techniques, processes, and technical details. There appeared to not be a corresponding emphasis on thinking about the teaching and learning process through questions such as: What concepts are being delivered through the activity? What are students actually learning and what parts of the process were most effective in causing this learning to occur? How might the lesson have been done differently to translate better into real classrooms? Might there have been an opportunity to connect and reinforce learning from other content areas? Engineering professional development should be designed to cause teachers to actively and routinely engage in this type of analytical and critical reflection on their teaching craft. Given the active, authentic, interdisciplinary nature of engineering content, there is real potential that the lessons learned through reflective practice could inform other disciplines throughout the school.

Conclusion

The body of work engaged in by the researchers has provided a substantial base for examining the current landscape of secondary level engineering professional development and synthesizing across the findings of several related activities. These activities resulted in the careful development of a research agenda and a clear articulation of the important issues for secondary level professional development. These issues need to be dealt with through rigorous research and thoughtful consideration. For example, the articulation of a conceptual base for engineering at the secondary level is an important step for the development of effective, comprehensive curriculum materials and teacher professional development programs. As the outcomes of the conceptual base study are disseminated to the larger educational community, further refinement of the concepts and articulation of core engineering processes and skills can occur.

With a defined conceptual base for secondary level engineering, studies must be conducted to explore how students learn engineering. Cognitive science, with its focused inquiry into how individuals acquire and process knowledge, has been used to help provide this understanding in other fields (Anderson, 1985; Reed, 2000). However, as Cross (2004) stated (focusing specifically on engineering design), there is “still precious little real understanding of the differences between novice and expert performance in design, and how to help students move from one to the other” (p. 429). This indicates a need for research outlining the learning progression involved in engineering design. In addition, Cajas (2002) stated that although there is some research on the procedural aspects of design, “there is practically no empirical research that can provide evidence of the conditions under which students learn key ideas about design such as trade-offs, constraints, etc.” (p. 181). Engineering-oriented curriculum and instruction should be based on research evidence of this kind.

This line of research is also crucial because it should have direct bearing on the design, implementation, and evaluation of teacher professional development. Student learning data should be an important input to the design of a professional development program (Loucks-Horsley et al., 2003). For example, the use of student work within the professional development experience has been shown to be an effective approach (Falk, 2001; Little, 2004). Lastly, evaluation, an ever-increasing important aspect of programs, should consider not only the impacts on the teachers’ practice but also on their and their students’ learning. As Fishman, Marx, Best, and Tal (2003) argued, “the most important measure of whether professional development is ‘working’ is whether teacher enactment yields evidence of improved student learning and performance” (p. 655). The learning targets and progressions should be research-based and fundamental to the design of curriculum, instruction, and teacher professional development.

Engineering at the K-12 level has tremendous potential for contributing to the vitality of the schools. In a world infused with technology, it is becoming increasingly important that students know something about the role of engineering in creating the technologies that they use. Active involvement in a democracy requires this kind of active awareness and participation, as citizens seek to make good consumer choices and voice their preferences at the ballot box. Further, for the U.S. to retain its competitive edge, it is vitally important that students be well prepared to access high tech careers in the STEM disciplines. In order for this potential to be realized, the preparation and ongoing development of teachers to teach engineering must be made a top priority.

References

Anderson, J. R. (1985). *Cognitive psychology and its implications* (2nd ed.). New York: W.H. Freeman & Company.

Cajas, F. (2002). The role of research in improving learning technological concepts and skills: The context of technological literacy. *International Journal of Technology and Design*, *12*(3), 175-188.

Cross, N. (2004). Expertise in design: An overview. *Design Studies*, (*25*)5, 427-441.

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597-604.

Daugherty, J. L. (2008). *Engineering-oriented professional development for secondary level teachers: A multiple case study analysis*. Dissertation, Department of Human Resource Education, University of Illinois, Urbana-Champaign.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis*, *24*(2), 81-112.

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review*, *14*(4), 532-550.

Falk, B. (2001). Professional learning through assessment. In A. Lieberman and L. Miller (Eds.). *Teachers caught in the action: The work of professional development* (pp. 118-139). New York: Teachers College Press.

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education*, *19*(6), 643-658.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.

Guskey, T. (1995). Professional development in education: In search of the optimal mix. In T. Guskey & M. Huberman (Eds.). *Professional development in education* (pp. 114-131). New York: Teachers College Press.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA.

Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education*, *16*(2), 37-54.

Little, J. W. (2004). 'Looking at student work' in the United States: A case of competing impulses in professional development. In C. Day & J. Sachs (Eds.). *International handbook on the continuing professional development of teachers*. (pp. 94-118). Berkshire, England: Open University.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics*. (2nd ed.). Thousand Oaks, CA: Corwin.

Reed, S. K. (2000). *Cognition: Theory and applications*. Australia: Wadsworth Thomson Learning.

Stake, R. E. (2006). *Multiple case study analysis*. New York: Guilford.

Wicklein, R. C. (2006). Five good reasons for engineering design as the focus for technology education. *The Technology Teacher*, *65*(7), 25-29.