2012

# Final Report: Accomplishments and Findings

NCETE Faculty

# Final Report

# Accomplishments and Findings

## 2004 - 2012

ncete™

National Center for Engineering and Technology Education
www.ncete.org

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

**National Center for Engineering and Technology Education**

**Final Report**
**(2004 – 2012)**

The National Center for Engineering and Technology Education (NCETE) was funded on August 15, 2004 under the auspices of the Centers for Learning and Teaching (CLT) program in the Division of Elementary, Secondary and Informal Education. The Program Solicitation (NSF 04-501) provided the following synopsis of the program:

> The Centers for Learning and Teaching program focuses on the advanced preparation of science, technology, engineering, and mathematics (STEM)educators as well as the establishment of meaningful partnerships with education stakeholders, especially PhD-granting institutions, school systems, and informal education performances. Its goal is to renew and diversify the care of leaders in STEM education; to increase the number of K-16 educators capable of delivering high-quality STEM instruction and assessment; and to conduct research into STEM education issues of national import.

The CLT program was discontinued shortly after NCETE was funded; consequently NCETE was the only CLT with a focus on K-12 technology and engineering education. The NCETE mission was:

> The National Center for Engineering and Technology Education is a collaborative network of scholars with backgrounds in technology education, engineering, and related fields. Our mission is to build capacity in technology education and to improve the understanding of the learning and teaching of high school students and teachers as they apply engineering design processes to technological problems.

A Changing Milieu

Economic, educational and political spheres have undergone significant changes since the 2004 funding of NCETE and have substantially influenced NCETE to amend its agenda for capacity building. The global recession that began in 2008 impacted institutions of higher educations in ways that were unimaginable in 2004. Academic programs with small enrollments were subjected to increased institutional scrutiny during the economic downturn, resulting in the elimination of the BS technology teacher education program at NCETE partner, North Carolina A&T State University and the merger of the Utah State University Technology Education program with Applied Science, Technology and Education in the College of Agriculture. Retiring NCETE faculty members at several institutions were not replaced consequently doctoral programs with emphases on technology education were phased out at the University of Minnesota and the University of Illinois Urbana-Champaign. As fewer faculty positions were available, it became more difficult to place NCETE fellows in research-intensive institutions.

Furthermore, funding shortfalls in higher education resulted in increased numbers of faculty members competing for NSF and DOE funding thus presenting another serious challenge for young faculty in technology education programs, especially those in teacher preparation programs without a history of securing external funding. The Center has conducted its program of work in this changing milieu and its accomplishments need to be viewed in that context.

Changes in the educational setting also influenced NCETE, in particular, the emerging role of engineering education within the high school setting. Engineering associations became interested in K-12 education in ways not seen in the previous century. For example, in 2003, the American Society for Engineering Education (ASEE) added the K-12 Division and initiated K-12 Workshops at the 2004 ASEE conference. In 2006, the National Academy of Engineering established the Committee on K-12 Engineering Education to explore K-12 engineering curricula and instructional practices. Their work was reported in the publication, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*.

An unresolved question is where engineering will ultimately fit within the K-12 curricula. The 2012 *Framework for K-12 Science Education* suggests that engineering and technology will be part of the new science standards. The National Assessment of Education Progress includes technology and engineering literary in its 2014 assessment as distinct literacies. In 2010, the International Technology Education Association changed its name to the International Technology and Engineering Educators Association (ITEEA) to address curriculum and professional development that includes both technology and engineering education at the K-12 level. In 2011, twelve states included engineering in science standards and one in mathematics standards, and nineteen states included engineering as related to standards promoted by ITEEA or Project Lead the Way.

Finally, the NCETE project was influenced by changes within the National Science Foundation. The name change from the Division of Elementary, Secondary and Informal Education to the Division for Research on Learning in Formal and Informal Settings characterized the shift in focus at NSF to educational research initiatives. The 2004 CLT solicitation described three equally important components: enhance the skills of current and future teachers, build capacity in STEM education, and support research in STEM education. Changes at NSF and within the Department of Education resulted in reduced emphasis on the component to “enhance the content knowledge and pedagogical skills of current and future element and secondary teachers.” The CLT component of “supporting research into STEM education issues of national import” was more strongly emphasized. The importance of “renewing and diversifying the cadre of leaders in STEM education” remained important. As a result, NCETE refocused its mission and goals. The new mission was to build capacity in technology education and to improve the understanding of the learning and teaching of high school students and teachers as they apply engineering design processes to technological problems.

## Accomplishments and Findings

NCETE was influenced by and also influenced the changing milieu described above. For example, designing and implementing professional development workshops for high school technology teachers was important only at the beginning of the grant, in part due to changing NSF priorities. Similarly, refocusing in-service technology teacher education programs was of importance only in the first two years of the grant. NCETE shifted emphasis from infusing engineering into technology education in K-12 to a focus on engineering design in high school STEM classes in response to changing priorities.

Throughout the life of the NCETE grant, there has been a consistent focus on capacity building. This report will describe NCETE capacity building accomplishments and findings for four groups: a) NCETE doctoral fellows, b) affiliated doctoral students and programs, c) NCETE faculty and d) the engineering and technology education community. The next section of the report describes accomplishments and findings relative to the NCETE professional development efforts. The report concludes with the accomplishments and findings of the NCETE efforts at developing research capacity.

## Capacity Building: NCETE Doctoral Fellows - Accomplishments

NCETE is pleased with the success of the cohort model for doctoral study in the four research institutions. In year one, the Center recruited a cohort of students who shared a number of common experiences during their doctoral programs, including course work and leadership development activities. The goal of the cohort model was to develop an enduring network among the doctoral students that would serve to support and encourage them during and after their doctoral experiences. Twelve students were recruited to the first cohort and began their doctoral programs in year two. Ten students were recruited into the second cohort and began their doctoral programs in year four.

NCETE partner institutions, North Carolina A&T State University and California State University Los Angeles, were effective participants in the recruitment of diverse students for both cohorts of fellows. Faculty members at both institutions mentored underrepresented students in the first cohort and are, in part, responsible for the excellent retention of underrepresented students in the first cohort.

NCETE faculty developed a two-year sequence of common courses especially for the fellows. Each semester, one course was offered by a doctoral-degree-granting partner institution using distance-delivery technologies to reach students at the other three doctoral sites. The common courses focused on cognitive science in engineering and technology education, the theoretical foundations of engineering design, and the application of engineering design. The first NCETE common course, The Role of Cognition in Engineering and Technology Education, was offered by University of Illinois at Urbana-Champaign. The majority of the course readings described empirical studies of cognition that focused on technical learning and thinking. The second NCETE course, Design Thinking in Engineering and Technology Education, was offered by the

University of Minnesota with an engineering perspective provided by Karl Smith (and by Gary Benenson during the second cycle). The course explored the concept that design is the primary conceptual anchor for technology education, drawing the subject ever more tightly toward engineering. The third NCETE course, Engineering Design: Synthesis, Analysis and Systems Thinking, was team taught by engineering and technology education faculty at the University of Georgia. The course provided the fellows with an academic experience that fostered critical questions as well as recognition and identification of potential issues associated with infusing engineering design into K-12.The fourth NCETE course, Engineering Design in STEM Education, focused on the integration of engineering design principles via engineering design challenges through research, development, and evaluation in grades 9-12 engineering and technology education. It was team taught by engineering faculty at California State University, Los Angeles and technology education faculty members at Utah State University and Illinois State University. Concepts explored in the course included curriculum development; students as learners and teachers; and engineering problem solving, analysis, modeling, optimization, and design.

Following the first offering of the common courses to the first cohort of fellows, NCETE faculty worked together to improve the common courses offered to the second cohort of doctoral fellows. Common course modifications were based on feedback both from an internal evaluation and from the report of the external evaluators. One significant change in the sequencing of the common course was the inclusion of a formal introduction to engineering design, including opportunities to engage in engineering-like design experiences, early in the common course sequence.

NCETE faculty and fellows were invited to participate in an internal research program beginning in the first year. Research proposals were solicited and reviewed and the highest rated proposals were funded. In addition to the internal research program, NCETE fellows also developed proposals to request funding for their dissertation studies. As the center evolved, it became clear that it would be advantageous to provide support for the exploratory research efforts of newly-employed professors, since none of them found a faculty position as part of an on-going funded research team. NCETE initiated an internally-funded grant competition, anonymous external reviewers rated the proposals, and several awards were made to recently-graduated fellows. These awards strengthened their early postdoctoral research endeavors and help them initiate their personal research agendas in their new tenure track positions.

In addition to the common courses and the cohort model, there were many other doctoral program experiences that were intended to build leadership, such as events where Fellows met in Washington DC, visited NSF, and met and spoke with NSF program officers; research sessions, where Fellows were introduced to key researchers in the field, as well as new researchers outside the Center; NCETE Center meetings, where many fellows were invited to participate in Center-wide planning and business meetings; support with proposal writing for their dissertations and other research opportunities; and internal grant opportunities. In general, the Center played a significant role in providing students with opportunities to build their confidence and skills in leadership.

Capacity Building: NCETE Doctoral Fellows – Findings

The cohort model of the doctoral program was a significant positive contributor to the students' experience, and to their perceptions of themselves as becoming leaders in the field. Twelve NCETE fellows completed their doctoral degrees. Of the twelve, three are African American males, one is an African American female, two are white females and six are white males. Even with the downturn in funding in higher education, eight of the twelve fellows are in tenure-track positions at the following institutions: Purdue (3), North Carolina State University (2), University of Idaho (1), Minnesota State University – Mankato (1), and the University of Wisconsin – Stout (1). One fellow took a position as Director of a Career and Technical Education Center in Alaska. Two fellows are adjunct faculty at regional institutions and one fellow is a post-doctoral teaching assistant at a research intensive university. Three NCETE fellows continue in "all but dissertation" status at their respective institutions.

The cohort model was especially successful for the first cohort, all of whom began their programs during the same semester and completed their dissertations in good time. NCETE fellows across institutions supported each other through out their doctoral programs and many remain closely connected. Formal and informal interactions across doctoral institutions strengthened the overall NCETE doctoral program. Most of the students were given opportunities to participate in research initiatives in addition to their individual dissertation research. Some students participated in research within their university departments; some students participated in NCETE sponsored research; and some students proposed and received internal grant money for research.

NCETE fellows developed NSF-like proposals to fund their dissertation studies. Following a critical review by faculty across NCETE, and an occasional rewrite, all proposals were funded. A retrospective review of the dissertations completed provides strong evidence that the provision of funding for dissertation research greatly improved the quality of the dissertations by enabling students to carry out more rigorous research. The evaluators concluded that the NCETE fellows submitted some of best dissertations in the technology education profession.

Reflecting on the NCETE fellows program, several activities might have been more successful if they had been implemented differently. NCETE garnered enthusiasm from the faculty in the doctoral-granting programs. However, the fellowship program would have been more successful if the doctoral institutions' departments and colleges could also have given priority to the NCETE mission and goals and expectations. For example, it was intended that all doctoral fellows would be recruited with the expectation that their MS degrees were completed. Some institutions, however, were willing to admit an individual to the PhD program prior to completion of the MS degree. In hindsight, it would have been wiser if these students had not received the NCETE fellowship until their MS thesis was completed. It was difficult for them to begin their doctoral work while they were concentrating upon completing their master's theses; the doctoral work suffered. In some cases, fellows were also expected to teach courses to help cover instruction in the pre-service teacher education program. Certainly some teaching experience was valuable for the doctoral fellows, but in some cases, the teaching requirement seemed excessive. Also, the teaching requirement was often in the area of traditional technology education, e.g. teaching a wood-manufacturing course, which did not contribute to the doctoral fellows' growth in the emerging area of engineering and technology education.

The doctoral fellows received a stipend of $20,000 per year, which was below the maximum allowed by NSF (at the time, $30,000). This lower stipend was considered to be typical for technology graduate programs but was probably a limitation for recruiting high-caliber doctoral students. In retrospect, it could be that a higher stipend level would have been appealing to potential recruits for the second cadre.

The recruiting model worked well for the first cadre. One of the priorities of the first year of the grant was a national recruiting effort. Both CSULA and NCA&T were able to assist in recruiting their outstanding MS candidates for the doctoral fellowship. Recruiting the second cohort could not be given the same priority as recruiting the first, since the doctoral institutions were already serving the first cohort with courses, advisement, and research planning. Consequently, individuals for the second cohort of fellows were essentially recruited locally by each of the doctoral institutions, with diminished support from CSULA, NCA&T, and the other teacher education institutions. The result was a weaker second cohort with fewer students able to complete the program. Also, NCETE lacked clearly-stated policies and procedures for replacing students in the first cohort who left the program or did not do well in it. A few replacement doctoral students were admitted who were out-of-phase with their peers in the common course offerings. These students enrolled in the third common course without the benefit of the first two. Furthermore, since they were between cohorts, they did not receive the full benefit of interactions with either cohort.

Capacity Building: Affiliated Doctoral Students and Programs - Accomplishments

In addition to the success in preparing the NCETE Fellows, one of the Center's accomplishments was to build capacity among other graduate students involved in engineering and technology education programs at NCETE-identified institutions as well as institutions not originally named in the grant.

Internal grants were available to all graduate students and faculty affiliated with a department that supported NCETE faculty. Several affiliated doctoral students were award internal grants and are currently in tenure-track positions in engineering and technology education programs. NCETE sponsored several Pre-Conference Workshops prior to International Technology and Engineering Educators Association Conferences. Presentations and papers at the workshop provided an opportunity for participants to describe progress on their internal grant programs. Several of the attendees reported on their recently funded NSF projects that often built on preliminary findings from the internal grant program.

NCETE supported a conference for doctoral students in engineering and technology education in year four. NCETE fellows were joined at this conference by doctoral students from Tufts

University, Virginia Tech, Colorado State University, Purdue University, and The Ohio State University. All doctoral students who attended were asked to present papers describing their dissertation research in progress.

Beginning in 2010, NCETE sponsored a seminar series that featured researchers in the field of engineering and technology education. The seminar included universities with doctoral programs in engineering and technology education. The purpose of the seminar was to build capacity with doctoral-degree institutions by exposing graduate students to current research on engineering and technology education at the secondary and postsecondary levels, and to create a networking opportunity for faculty and graduate students at selected doctoral granting institutions. Participating universities included: Colorado State University, Purdue University, University of Georgia, University of Illinois at Urbana-Champaign, Utah State University, and Virginia Tech. The first three seminar series have been very successful and the faculty from all of the partnering institutions indicated that they would like to continue the seminar series in 2013. Currently, plans are underway to determine the 2013 theme for the seminar series and research topics to be explored.

NCETE continued to develop research capacity across engineering and technology education programs by co-sponsoring the 2$^{nd}$ P-12 Engineering and Design Education Research Summit which brought together researchers in the field of P-12 engineering education research. The goals of the Summit were to develop engineering education research capacity and included: (1) a doctoral consortium, which provides Ph.D. students with the opportunity to receive mentorship and individual feedback on their proposals and (2) sessions which function as workshops to provide professional development opportunity for staffers and researchers. NCETE and the Institute for P-12 Engineering Research and Learning, Purdue University, co-sponsored the Summit.

NCETE invited several promising young investigators at the post-doctoral level and at the assistant professor level to participate in the 2012 Caucus on Engineering Design Challenges for High School Students. One of the reasons for including these young investigators was to provide them with an opportunity to network with prominent engineering educators, curriculum developers, cognitive scientists, and professional development providers.

Capacity Building: Affiliated Doctoral Students and Programs – Findings

Extending the internal grant process to include doctoral students at partner institutions was successful. Among the non-NCETE fellows receiving grants, Oenardi Lawanto and Paul Asunda are establishing successful careers in engineering and technology education programs. Their current research programs are building on the research they were able to conduct with the internally-funded grants.

The seminar series has been very successful over the past three years partly due to the quality of the presentations, but also due to the continuous improvement process put in place for the seminar. At the end of each seminar series, time was allocated to determine what participating faculty and graduate students thought of the experience and how to improve future seminars. Questions were asked of the participants in an open forum and time was given for feedback. The questions were formulated by the organizing faculty at each participating institution. In addition to logistical questions about quality of IP video technology and time of day for the seminar, several questions were asked that were used to plan for the next seminar series. Throughout the three year offering of the seminar series, technical challenges haunted the series. Technical problems associated with synchronous delivery to multiple sites are not unusual. The seminar facilitators did not always have alternative plans for technical glitches and the associated down time. The strength of the seminar series was presentations by well-known researchers, but this was occasionally problematic because some presenters delivered teacher-centered presentations that did not include interaction among graduate students.

The internal evaluation of the Second P-12 Engineering and Design Education Research Summit indicated that implementation of the 2012 PK-12 summit could be characterized as meeting or exceeding expectations. For the most part, summit speakers and facilitators were knowledgeable, engaging, and adhered to the expectation of significant interaction with the audience.

Capacity Building: NCETE Faculty – Accomplishments

NCETE hosted a series of multiple-day meetings with a focus on faculty development. A number of meetings were facilitated by NCETE faculty and held at NCETE sites. For example, NCETE participated in the 53rd Stout Technology Education Conference. Another example of an NCETE-internally-focused meeting was an event held at Utah State University where several NCETE colleagues introduced a design challenge to the Center.

Several of the meetings introduced NCETE to researchers outside of the traditional technology education circle. One meeting introduced NCETE to Martha Cyr and her work in engineering design. Another meeting introduced NCETE to Christine Cunningham and Janet Kolodner. Christine Cunningham reported the findings of her work on the recruitment of girls and women to engineering and technology. Janet Kolodner described her investigations of effective ways to implement design activities in the classroom.

In order to develop research capacity within NCETE, another summer workshop included a research symposium that provided faculty and fellows with a comprehensive look at the outcomes of the first cycle of seed-grant research funded by the Center. The symposium program consisted of fellows and faculty members reporting on the findings of the six seed-grant studies funded during the first year of Center operation. The symposium included a critique of the funded studies to improve research methodologies and implications of their findings. A member of the NCETE advisory board had suggested the research critique because it was very successful in improving elements of a science education program. Another meeting included presentations by three former journal editors who reflected on changing the technology education culture to a research paradigm, mentoring students and young faculty, taking cues from other fields, and promoting research interests.

Capacity Building: NCETE Faculty – Findings

The multiple-day professional development meetings were moderately successful. Events facilitated by NCETE faculty were the most successful based on feedback from NCETE colleagues. Grant resources permitted NCETE to provide enriching programs that introduced the teacher education faculty to active research efforts focused on infusing engineering design into STEM instruction. These meetings were viewed as less effective by NCETE colleagues. NCETE met with moderate success in overcoming resistance to ideas from people outside of technology education, especially those working with elementary and middle schools.

The symposium that included a critique of internal research studies was particularly threatening to NCETE faculty. The notion of introducing a “critique” component to the research review element of the symposium was met with considerable resistance within the technology education community. A number of investigators were not comfortable defending their choice of methodology or the relevance of their findings.

Capacity Building: Engineering and Technology Education Community - Accomplishments

The original proposal developed by NCETE did not include post-doctoral students. As NCETE matured and developed a focused, well-defined research agenda, it was clear to the leadership team that much research capacity could be gained by hiring post-doctoral research associates. NCETE conducted two national searches for post-doctoral students with expertise in engineering and technology education. Ultimately, four of the NCETE doctoral graduates were interested in a post-doctoral research experience and were hired by the Center. Mentoring activities for the post-docs included assistance with the development and delivery of formal presentations for meetings of professional organizations. The post-docs also attended meetings of other professional societies where they were not expected to give a paper. Additional research-related activities of the post-doctoral research associates include the preparation and submission of scholarly manuscripts. The post-doctoral research associates also participated in a number of NCETE research and capacity building activities. In particular, they helped develop the on-line research seminar; conducted preliminary investigations into the development of a survey instrument to measure students’ self-efficacy, interest, and perceptions of engineering; and studied the approaches of teams of high school student confronted by engineering design challenges.

Early in the life of the Center, the NCETE Advisory Board played an important role in shaping the work of the Center. The Advisory Board was particularly influential following the reverse site visit. As the research agenda and the doctoral program matured, NCETE found the collective advice of the Board to be less valuable compared with focused advice from selected Board members on very specific topics. For example, select Board members participated in the review of the NCETE internal research program. Since they were aware of the history of NCETE and the development of the research agenda, they could provide both the proposer and the leadership team with credible and achievable advice on ways to improve the proposal.

Throughout the life of the Center, faculty and doctoral students were encouraged to participate in conferences. Early, the work of NCETE was visible at the International Technology Education Association annual meeting. NCETE encouraged fellows to participate in poster sessions and hosted pre-conference research meetings. Recently, NCETE has increased its visibility at the American Society for Engineering Education (ASEE) annual conference through authorship of presented papers and organized dinner meetings. Even though there is a growing K-12 presence in ASEE, many of the original NCETE faculty and students continue to present their work at annual ITEEA meeting.

Invited papers provided a mechanism for NCETE to improve research capacity. NCETE commissioned a broad cross-section of experts to provide brief descriptions of guidelines for the infusion of engineering design challenges into STEM courses for all students. The papers were authored by recognized experts in the area of engineering design including: Arthur Eisenkraft, David Jonassen, Chris Rogers, Christian Shunn, Cary Sneider, and Johannes Strobel. The papers are posted on the NCETE website and provide a valuable resource for individuals conducting research focused on engineering design.

Over the past two years, NCETE continued to broaden the circle of collaborators working in the area of high school engineering design by hosting two Caucuses. Ten individuals who were early innovators in introducing engineering design activities in high school STEM settings were invited to each Caucus. Both Caucuses were held on the Utah State University campus in Logan; the first on August 2 and 3, 2011 and the second on May 22-24, 2012. The invited papers and an annotated bibliography were made available to the Caucus participants to provide background information. The Caucus groups engaged in intensive dialogues during their on-campus sessions, prepared statements on aspects of the development and selection of authentic engineering design challenges, and suggested revisions of successive drafts. The outcomes of the two caucuses were synthesized and resulted in a paper, “Incorporating Engineering Design Challenges into STEM Courses,” which is available on the NCETE website. The paper is an exploration of the available research on the following questions dealing with the implementation of engineering design challenges in high school STEM courses. The paper is intended to provide guidelines for the development of authentic engineering design challenges, to describe instructional strategies for introducing engineering design experiences to high school students, and to offer suggestions for the assessment of the outcomes of engineering design activities. The information is intended to be useful in planning, organizing, and implementing the infusion of engineering design challenges in high school STEM courses. The paper is not intended as a detailed guide for curriculum development, comprehensive instructional design, or the assessment of achievement across the range of high school STEM courses.

Capacity Building: Engineering and Technology Education Community - Findings

The post-doctoral research program was very successful in developing research capacity. Currently, three of the four post docs are Co-PIs of funded DRK-12 projects and the fourth post-doc is now a PI on a collaborative project. Their records of publications and presentations, as well as their performance in their faculty roles, seem to have been strengthened by the post-doc experience. NCETE had limited success in finding post-docs through two national searches. One of the problems is that the pool of engineering and technology education doctoral students was small. NCETE personnel were on a learning curve about how to work with post-doctoral students. It appears that the NCETE post-doctoral students were among the first post-docs in technology education. NCETE did not have a strong ongoing research agenda that the post-doctoral students built upon. Rather the post-doctoral fellows were responsible for helping define the NCETE research agenda.

The Advisory Board was very helpful at the start of the center in helping the Center become organized and develop operational guidelines. The Advisory Board was never institutionalized, there was not a charter or mission for the board or a description of what the board might do for the Center. Consequently, the Board provided a range of responses from micromanagement to lofty visions depending on the board member. As the Center moved forward, it seemed more useful to capitalize upon the individual consulting capabilities of the diverse individuals. Some of Board members have continued to assist the Center throughout its life.

NCETE presentations are still heavily tilted toward ITEAA; however, there have been substantial inroads into ASEE presentations for the past several years. The first proposals to AERA occurred late in the life of the Center – modest progress toward attainment of the level of research competence expected from scholars in educational research.

The Center's best efforts included Caucus I, Caucus II, and the Invited papers that focused on engineering design challenges appropriate for high school learners. The Center facilitated the interaction among many experts in the area of high school engineering design. NCETE assembled a research community of investigators interested in high school engineering design and helped them work toward consensus and unity of purpose related to engineering design in the high school.

Professional Development: Movement Toward an Exemplary Program

NCETE examined elements of professional development (PD) for high school teachers. During the first two years of the Center, this work was conducted at five NCETE teacher education institutions with each institution examining a potential model of professional development. At each site, university faculty members worked primarily with technology teacher but some sites included science and mathematics teachers interested in infusing engineering design into high school classrooms. Following guidance provided to NCETE during the reverse site visit, the "service" nature of the PD effort was de-emphasized. Synthesis of first two years of professional development activities and associated research studies provided guidance to the Center on essential features of effective PD. A year-long professional development (PD) program was developed, based on the experiences of earlier PD activities within the Center and the current body of research. The NCETE PD Model consisted of a long-term effort involving teams of STEM teachers; spring Saturday sessions and summer on-campus workshops providing experiences in working with engineering design; challenges and opportunities for the development of engineering design challenges suitable for each teacher's high school classes; classroom implementation of the design challenges during the subsequent academic year; and classroom visitations by members of the PD teams.

Two sites were selected to pilot the NCETE PD model: CSULA and NCA&T. Both sites had positive involvement from engineering faculty as content experts on the professional development teams and access to diverse teacher and student populations. CSULA had access to STEM academies through Long Beach Unified Schools and NCA&T had access both to STEM academies and to traditional science, technology, engineering, and mathematics programs. Most of the professional development work worked occurred during year five (2008-2009). An internal evaluation of the program offered evidence that the teachers who participated in the workshops increased their content knowledge in engineering design, were well served by the teams of professional developers, were quite pleased by the organization and conduct of the workshops, and were positive about the potential of engineering design activities to increase student motivation and learning in their high school science, technology, engineering, and mathematics courses. Some teachers expressed concerns about the time required to fully implement one of the design challenges, their students' mathematics and science capabilities, and the fit with their current curricula. Some of the teachers were challenged because of weaknesses in pedagogy or content knowledge. The mathematics teachers were challenged by the pedagogical issues related to students working in groups and moving around the room, while the technology education teachers were challenged by weaknesses in mathematics. The team of developers felt they may have placed too much emphasis on strict adherence to the predictive analysis model. While this is clearly a hallmark of engineering design, the PD team felt they overemphasized this facet rather than broadening the use of the model with an understanding that engineering design may sometimes rely on intuitive mechanical design.

NCETE personnel learned that developing effective professional development is much more complicated than originally conceived during proposal development. Some of the challenges are associated with the recent emergence of engineering design as a subject of importance for high school students. There is no clear disciplinary, standards-based home for engineering design experiences. Currently, the infusion of engineering design into high school courses is scattered across mathematics, technology and science. What is the teacher pedagogical content knowledge that effective PD should support? There are limited curriculum materials available to guide teachers and professional developers.

Findings from an NCETE internally funded research investigation highlight the challenges faced by teachers as they guide their students in the development of engineering design habits of thought and action. The study was guided by the following research question: How do high school STEM teachers plan to implement engineering design in their classrooms? Researcher understanding of teachers' planned implementation emerged through the triangulation of data, which included teacher generated lesson plan documents and lesson presentations during the professional development. The sample of 17 teachers participated in the study representing science, mathematics, and technology education teachers who work under the constraints of standard-based curriculums. The investigators concluded that most teachers (14 of 17) who completed the professional development created lesson plans which involved the engineering design process. Teachers had difficulties encouraging their students to participate in all phases of the engineering design process, particularly in the area of defining the need and problem definition. Rather, teachers planned for a general shift in responsibilities as students progressed through the design process. In the early stages of the design process, teachers had the majority of responsibility for identifying the need and defining the problem. This may be attributed to the difficulty novice learners encountered by attempting to define the problem. Teachers planned to do most of the research and develop a limited set of designs with which the students might work. Student responsibilities increased as they began with a limited solution set and conducted analysis planned by the teacher. Students made a decision based on the analysis and tested their predicted results with experiments planned by the teacher.

Based on the work NCETE accomplished from two Caucuses held in 2011 and 2012, presenting students with opportunities to engage in engineering design requires a paradigm shift from the traditional classroom environment in which the teacher is responsible for providing the design challenge and then instructing the students on how to find the best solution to the challenge. Teachers need to learn how to establish an environment that encourages students to take ownership of the engineering design challenge, identify needs or wants that are personally important or relevant to them, frame the problem within applicable criteria and constraints, generate alternative solutions, evaluate competing ideas, and carry out the construction and testing of prototypes. A similar paradigm shift is required for teacher professional development. Effective PD is not providing the teachers with four or five "canned" design challenges for students. Rather, effective PD will help the teachers learn how to help the students select design challenges and how to manage the learning environment so that teams of students can find solutions to their challenges.

Research Capacity Building

At the time NCETE began, traditional doctoral programs in technology education offered individual graduate students wide discretion in the selection of topics and the specific direction of their research. Advisers rarely recruited doctoral students to carry out specific research efforts and few of the professors had funded projects designed to yield publishable results. When the first cohort of NCETE doctoral students began the development of their dissertation research proposals, none of their doctoral advisers had a funded research effort that could incorporate their doctoral research efforts in a programmatic way. The dissertation research was viewed more as an isolated academic exercise than a component of a concerted research effort involving colleagues, faculty members, and other collaborators.

When a first attempt was made to develop a research agenda to guide the work of NCETE, the search for consensus had to be set aside in favor of the creation of a comprehensive catalog of potential topics, a framework for research in the field. This listing lacked clear focus on any segment of the potential investigations in engineering and technology education, but served to help the group envision the potential landscape for the sorely needed program of research in the field. Almost immediately, the group initiated a request for proposals, initiating a competition open to faculty members and graduate students in the nine NCETE institutions. From that modest beginning, the NCETE internal research program has resulted in the completion of 33 studies. The combination of internal research funding and the professional development of NCETE faculty in the research process has enabled faculty and fellows to play key roles in over 20 active NSF awards.

One of the first efforts to strengthen research productivity involved funding a case study completed in 2005 by a doctoral student who was engaged in doctoral work when the Center was formed, and consequently had no opportunity to apply as an NCETE fellow. After completing that research and the doctoral requirements, NCETE funded this individual's exploratory research as a new faculty member. Subsequently, this researcher has received two NSF awards, including a CAREER award.

Two faculty members at an NCETE teacher education partner institution received a small NCETE award for their first post-doctoral research project. That effort led to a series of professional presentations and publications; the results provided major guidance to the development of the NCETE professional development model that guided NCETE's professional development initiative.

A series of small grants, beginning with a study by three fellows and two faculty members completed in 2007 and continuing with a series of five studies, the last completed in 2012, have contributed to the intellectual development of a DR K-12 Full Research and Development project currently under way.

Faculty and fellows also collaborated on joint research projects. These resulted in DR K-12 exploratory projects on design thinking in engineering and technology education and on the influence of a co-curricular program on underrepresented students' perceptions of engineering and interest in engineering.

NCETE support for faculty research has enabled researchers to conduct pilot investigations of the role of student interest in authentic research design challenges. Preliminary findings from that research contributed to the development of a proposal for a recently funded DR K-12 exploratory project on community-based engineering design challenges for adolescent English learners.

Summary

The National Center for Engineering and Technology Education has made significant contributions toward the comprehensive effort to provide all high school students with experiences in engineering design. Professional development efforts have strengthened the preparation of current and future teacher educators, researchers, and instructional designers. The NCETE research effort has led the professional response to emerging needs in the field, has recognized evolving opportunities for increasing understanding of the learning and teaching process, modified personnel plans to adapt to changing circumstances, and enhanced professional communication in the engineering and technology education community. Future generations of American youth will benefit from its catalytic efforts to enhance the engineering and technological literacy of individuals from all walks of life.