The Center for Advancement of Engineering Education: A Description at Year 2

Cynthia J. Atman, Jennifer Turns, Robin Adams, and Reed Stevens, University of Washington, Seattle, WA; Lorraine Fleming, Howard University, Washington, DC; Larry Leifer and Sheri Sheppard, Stanford University, Stanford, CA; Karl A. Smith, University of Minnesota, Minneapolis, MN; and Ruth Streveler, Colorado School of Mines, Golden, CO

There are critical national needs to advance scholarship in engineering teaching and learning, increase the use of effective pedagogies in engineering classrooms, and strengthen the research and leadership skills of the engineering faculty and graduate student community. The mission of the Center for the Advancement of Engineering Education (CAEE) is to address those needs.

CAEE is an NSF-funded higher education Center for Learning and Teaching that began in January 2003. The five-year grant is funded by both the Directorate for Education and Human Resources and the Directorate for Engineering (ESI-0227558).

CAEE brings together a team of scholars with diverse backgrounds and disciplines from five campuses: Colorado School of Mines, Howard University, Stanford University, the University of Minnesota, and the University of Washington, the lead institution. In addition to the core partner campuses, the center has a wide range of affiliates, including other academic institutions, national organizations, and industrial partners.

The work of the center is embodied in five overarching goals:

- Understand and enhance the engineering student learning experience.
- Integrate the needs of diverse faculty and diverse students into engineering education.
- Strengthen the engineering education research base.
- Expand the community of leaders in engineering education.
- Promote effective teaching for current and future faculty.

These five goals will be realized through the interaction of three interdependent research focus areas called elements. The three elements are Scholarship on Learning Engineering (SoL), Scholarship on Teaching Engineering (SoT), and Institute for Scholarship on Engineering Education (ISEE).

The center's strength is its ability to facilitate a high level of interaction among the teams of scholars in the center's elements. This dynamic collaboration of CAEE team members will enable the teams to capitalize on each other's results, test and incorporate findings quickly, and generate a rich body of work. The three elements bridge the five partner campuses, creating multiple opportunities for collaboration. The ultimate result of this structure is an environment in which investigators have an awareness and involvement in each other's work and share a commitment to work together toward common goals. The following sections describe the work of the three CAEE elements.

Scholarship on Learning Engineering (SoL)

Overview

The primary objective of the SoL element is to conduct research on the engineering learning experience to provide a comprehensive account of how people become engineers, thereby creating insights into key questions in engineering education. This research will enable a better understanding of how engineering students navigate their education (successfully or unsuccessfully), explore how misalignments between university and workplace practices affect preparation and retention, and describe how students' learning and working environments intersect with engineering. The studies will help educators understand how engineering learning and educational experiences vary across populations and institutions, identifying significant factors related

to gender, ethnic, and geographic diversity.

The SoL element consists of two parts: the Academic Pathways Study (APS) and three smaller-scale targeted studies.

Academic Pathways Study (APS)

APS consists of four cohorts. Cohort 1 is a longitudinal study of student participants across four institutions (Colorado School of Mines, Howard University, Stanford University, and University of Washington). Cohorts 2–4 extend the studies to include additional students on the four campuses and at CAEE affiliate institutions. The study involves data-gathering and analysis, interpretation and dissemination of the research data, and findings from these four interrelated and complementary cohorts. In addition, implications of findings for existing faculty, program, and institution practices will be explored at the four institutions and beyond.

The study uses three primary investigative tools: surveys, in-depth interviews, and ethnographic observations. Surveys and interviews provide data on a large set of participants, whereas ethnography provides a deeper level of information on a more limited number of subjects. Each tool provides a set of insights that informs the other tools, allowing generalization of specific findings to a broader population.

The four cohorts are as follows:

- **Cohort 1.** For Cohort 1, the researchers will follow students from their first year through junior year, with a goal to learn how incoming first-year students navigate the precarious early years of an engineering major, which often include the decision to continue or abandon their plans to study engineering. Cohort 1 will consist of 40 participants from each of the four campuses for a total of 160. In addition, there is a control group at each school, ranging from 20 to 40 students (depending on the size of the first-year student body at the school). All 160 participants will participate in surveys and interviews, while the control group will have no direct observation. Eight of the 40 participants at each campus will also be ethnography participants, for a total of 32 ethnography subjects.
- **Cohort 2.** The research team will follow students in Cohort 2 from the end of their junior year through the first year post-BS, focusing on the critical transition from undergraduate education to either the workforce or graduate school. Studying Cohort 2 will help to identify what aspects of the development of an engineer are not taught or learned in an undergraduate education. Cohort 2 will have 16 participants from two of the four institutions: 8 from Howard University and 8 from the University of Washington. Cohort 2 participants are to be followed from April 2005 through June 2007.
- **Cohort 3.** Cohort 3 will include all participants from the first two cohorts and additional students from the four institutions. The team will administer surveys based on research findings to date to Cohort 3 participants. The data collected will allow the team to generalize from cohort 1 and 2 findings and compare results from a broader range of students. Cohort 3 will involve 2,000 or more students.
- **Cohort 4.** Cohort 4 will include students from engineering programs at collaborating institutions across the country. The team has selected these institutions to ensure a diversity of educational experiences and student populations in the studies. Studies of Cohort 4 participants will follow the study of Cohorts 1, 2, and 3 and will focus on the same questions as these cohorts but use different methods. The Cohort 4 studies will help ensure that the images produced of how students at U.S. institutions become engineers are diverse and as representative as possible. Cohort 4 will consist of 3,000 (or more) participants.

Targeted studies

The three targeted studies conduct research on core components of engineering knowledge and practice and aspects of the discipline that are considered to be central to what it means to become an engineer. The results of the targeted studies research will be used to inform faculty decisions on how to teach engineering concepts to students more effectively.

The three targeted studies are as follows:

- **Difficult concepts.** This study at the Colorado School of Mines maps the concept space of engineering students. Lists of difficult concepts in engineering mechanics and circuits are generated by experts in the field, validated by student interviews, and then used to develop a reliable, valid, and unbiased concept inventory in one of the two areas. Twenty engineering faculty from each discipline will participate in separate Delphi studies to reach consensus about widely held student misconceptions. One or more

conceptual or computational questions will be validated through think-aloud sessions, expert review, and interviews with students to generate the concept inventory.

- **Technological Fluencies in Becoming an Engineer.** This study at the University of Washington (UW) seeks to understand the technological fluencies 1) brought by students to educational activities and 2) developed through engineering instruction. Technological fluencies of engineering students will be documented and compared with those in professional engineering settings. Students' comprehensive technology use will be surveyed, and student case studies will be created in different engineering programs, with comparisons made to documented engineering practices found in professional settings.
- **Role of Mathematics in Engineering Education and Practice.** Mathematics is an important tool in the practice of engineering work and also an acknowledged gatekeeper. Anecdotal evidence suggests a significant misalignment between the mathematical requirements of work and education (at the undergraduate or graduate levels). This study at UW will explore these alignments by conducting strategic ethnographic and interview-based studies across the divide between engineering education and professional work. Building upon the cohort 1 studies of the APS, the study will seek to catalog the mathematical demands of an undergraduate education in engineering. Interviews and short-term ethnographic field visits will be conducted with practicing engineers to explore the mathematics that they use. A comparative analysis of these mathematical practices will be conducted as a final stage of this project.

Scholarship on Teaching Engineering (SoT)

Overview

The mission of the SoT element is to enhance the effectiveness of strategies used to help educators improve their teaching. The Scholarship on Teaching team is committed to the use of scholarly approaches to defining this design challenge and to evaluating proposed solutions. Specifically, the SoT element seeks to 1) understand how current and future engineering educators make teaching-related decisions, 2) demonstrate how a decision-making perspective and knowledge about engineering educator decision-making can be used to enhance teaching, and 3) design and rigorously evaluate a program in which engineering graduate students engage in teaching portfolio development as a means of preparing for the teaching responsibilities of a faculty career. These goals are instantiated in two threads of activity, the Studies of Engineering Educator Decisions (SEED) and the Engineering Teaching Portfolio Program (ETPP).

Studies of Engineering Educator Decisions (SEED)

The Scholarship on Teaching element will provide the engineering education community with insight into the ways engineering educators make decisions. The researchers will do this using rigorous research approaches across a series of four studies. By using multiple methods across the studies, the studies will create a picture that has both breadth and depth, provides both retrospective and current behavior, and reflects institutional differences in decision-making. The insight gained through the studies will enable the entire community to more effectively support the advancement of engineering teaching.

Phase 1 of the research will use interviews to explore self-reported decisions and will focus on developing a strong initial understanding of how engineering educators make decisions in the context of their teaching. A phone interview study (approximately 40 participants) will be conducted, involving educators at the CAEE partner campuses. Educators will be asked to talk about decisions they make in the context of their teaching to provide an understanding of the types of decisions they make, the types of information they use to make these decisions, and the process by which they make the decisions. Phase 2 will build on the findings of the interview research by conducting a web-based survey (estimated 350 participants) that will reach engineering educators across the country. Through the survey, information will be collected on the teaching strategies and resources that educators currently use and their sense of teaching as a decision-making process. Phase 3 will complement the self-reported data of the interviews and web survey with observation-based insights with five subjects. Naturalistic research methods will be used (e.g., ethnography, field work) to understand how engineering educators make decisions in the context of their teaching. The selection of contexts (e.g., which classes, which aspects of teaching) and emphases (e.g., which decisions) in this study will draw from and complement the phase 1 and 2 studies as

well as findings from ongoing research of the SoL element. Phase 4 will focus on exploring mechanisms for bringing the research findings into educational practice (with approximately 10 participants). Specifically, one or more methods will be developed that help educators connect research findings to potential/actual decisions. These design experiments focus on aspects of decision-making and opportunities for intervention that have been foreshadowed by the research to date. Various mechanisms will be designed and evaluated to help educators connect preceding research findings to potential/actual decisions.

Engineering Teaching Portfolio Program (ETPP)

The ETPP will help engineering graduate students document and reflect on their teaching, with a goal of continuous improvement. Decision-making will be a theme in the portfolio program, with a goal of making the decision process more visible and deliberate. The initial activities will focus on engineering graduate students, first at UW, and later at the CAEE partner institutions and with graduate students associated with center affiliates. This focus on the next generation of engineering faculty will ensure that the efforts will have a long-term impact. Participants in the portfolio program will gain a better sense of the responsibilities associated with a faculty career, a better understanding of the impact that teaching decisions have on students, and a broader perspective of scholarship.

Participants in the program will work in peer-facilitated groups to create and revise teaching portfolios. The activities in the program will help participants to 1) develop a shared understanding of teaching portfolios; 2) write a personal philosophy of teaching; 3) compose a personal philosophy on diversity in higher education; 4) identify items to include in a portfolio, e.g., assignments, syllabi, evaluations; 5) select and annotate teaching artifacts that support their teaching and diversity statements; and 6) assemble a draft portfolio. Throughout this process, participants will have opportunities to provide and receive peer feedback. As part of the program development, the researchers will assemble resources to support the activities (e.g., resources describing teaching portfolios, philosophy writing strategies, annotation guidelines, example philosophy statements, example portfolios). It is anticipated that activity will be distributed over the following four phases.

Phase 1 of the program will focus on the design and formative evaluation of the program. The formative evaluation will involve collection of data using multiple data collection methods (e.g., field notes of sessions, interviews with participants) to gain a detailed and comprehensive account of how the program transpired across and within individual participants. **Phase 2** will focus on evaluating the impacts of the program on participants and understanding what is needed to adopt the program under varied circumstances. To do this, the portfolio program will be made available to graduate students at UW and Howard University, and the researchers will work with various student groups to adopt and adapt the portfolio program to suit their institutional contexts. **Phase 3** will bring the program to other universities and educational contexts throughout the nation. The program and collected guidelines for adaptation will initially be made available through the web. A variety of strategies will be used to help groups around the nation to gain awareness of the program and work on instantiating the program in their institutional contexts. In these cases, the researchers will encourage groups implementing the program to share information concerning the process and outcomes of their instantiation of the program. **Phase 4** will focus on collecting data to confirm findings concerning the impact of the program on participants and the adaptability of the program in multiple contexts. Validation studies will be focused on the CAEE partner institutions (UW, Howard, Colorado School of Mines, and Stanford).

Throughout this work, the researchers anticipate working with a minimum of 70 graduate students over the duration of the CAEE grant. Specifically, there will be at least 10 UW graduate students during the first phase of activity, at least 10 UW and 10 Howard graduate students during the second phase of activity, and at least 10 graduate students at each of the four partner institutions during the final phase. Efforts during phase 3 will further increase this number.

Institute for Scholarship on Engineering Education (ISEE)

Overview

The objective of the ISEE element is to cultivate, foster, and sustain a national community of engineering education scholars through annual occurrences of the ISEE. Each year-

long institute is designed to 1) foster a scientifically competent community of education researchers and change agents capable of conducting substantive research and bridging research activities with education practice, 2) facilitate greater coherence within the existing community as well as cross-disciplinary collaborations, 3) educate the profession on the practice of education research, and 4) contribute to increased visibility and recognition of the value of engineering education scholarship. The institutes are designed to identify models and design requirements for guiding future investments in the research infrastructure.

ISEE will be hosted at different CAEE campuses in successive academic years, starting with UW (2004–2005), then Stanford University, and then Howard University.

Stages of the institute year

The Engineering Education Institutes are comprised of five cyclic activities:

- **Stage 1: Recruiting and selecting scholars.** Each year of the institute includes honorariums for 12 faculty and three graduate students and opportunities for four CAEE graduate students and postdoctoral research associates to participate. The selection and review process emphasizes recruiting diverse participants and includes active involvement from CAEE partners and affiliates.
- **Stage 2: The Summer Summit.** The Summer Summit is an intensive and interactive learning experience at the beginning of the institute year at the host campus. Scholars will learn research methods, identify opportunities for "bootstrapping" research interests into the SoL element's studies, formulate a research proposal, and develop as a community.
- **Stage 3: Conducting a year-long research study.** During the academic year, scholars will conduct a year-long research study. The year will include activities to sustain the community such as formal meetings, mentoring (experts and peers), and small-scale projects to inform study activities, support a richer understanding of research concepts, and discuss leadership issues.
- **Stage 4: The Leadership Summit.** The culminating event of the institute year is a Leadership Summit in which scholars present their work, are introduced into the broader engineering education community, and refine leadership skills.
- **Stage 5: Mapping and Adapting the Institute.** The final stage involves distilling what has been learned, identifying opportunities for continuous improvement, and aligning the institute model with the needs of the next host campus. Through this process of documenting the effectiveness of the model, as well as the challenges encountered and the resources leveraged at the different campuses, the team will formulate design requirements that will guide the transition to each host campus.

Conclusions

The CAEE team collaborates across institutions and elements to work toward achieving the center goals. Team members from each element conduct research on many aspects of the engineering education enterprise. This collective effort will strengthen the research base in engineering education. One major focus for research in each element is on understanding the students, both undergraduate and graduate. This understanding, in turn, will enable the community of engineering educators to design and deliver more effective learning experiences for the students. Throughout the work, there is a core commitment to meet the needs of students and faculty from underrepresented populations in engineering. And finally, the in-depth work on each campus and the efforts of the institutes will help to expand the community of scholars in engineering education who will be contributing to each of the other four goals into the future.

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