*Special Report*

# The National Engineering Education Research Colloquies

THE STEERING COMMITTEE OF THE NATIONAL ENGINEERING EDUCATION RESEARCH COLLOQUIES

## I. THE PROCESS

Will the U.S. have engineers prepared to collaborate and lead in a rapidly changing world? The answer to that question, in part, relies on our ability to transform how we educate our future engineers. Our premise is that we need fundamental knowledge of how engineers learn to under-gird these transformational decisions. With support from the National Science Foundation, the Engineering Education Research Colloquies (EERC) were designed to collaboratively develop a national research framework and agenda to conduct rigorous engineering education research. The endeavor represents the collective effort of more than seventy engineering, science, and mathematics education researchers, learning scientists, and practitioners who worked together during three face-to-face meetings. All of the individuals who actively participated in the creation of what we now present as the research areas for the new discipline of Engineering Education are acknowledged below. A summary report of their effort appears in the article that follows.

The article describes how the five priority research areas (Engineering Epistemologies, Engineering Learning Mechanisms, Engineering Learning Systems, Engineering Diversity and Inclusiveness, and Engineering Assessment) came to fruition. Participants in Colloquy One used a reverse roadmap process with progressive refinement to identify major engineering education research themes. The process used in excess of fifty-five desirable outcomes (i.e., competencies and attributes) of a graduating engineer as the discussion starting point. Three categories of outcomes were identified: established outcomes (those that are defined by ABET EC2000 and have already been widely discussed in the engineering education community, e.g., teamwork, communication skills); emerging outcomes (those that are newly identified in the literature and are currently part of the national debate, e.g., the nature of innovation, practical ingenuity); and opportunity outcomes (future outcomes that are being discussed locally or will be required to advance the future of engineering education, e.g., understanding globalization and its impact on the workforce, dealing with setbacks and failure).

The list of engineering education research themes developed during Colloquy One served as the starting point for the next colloquy. Participants in Colloquy Two used a COGS (Challenges, Opportunities, Gaps, and Strengths) analysis to transform the research themes into nineteen explicit research clusters. These nineteen research clusters were then synthesized during a third EERC meeting. The results of this final meeting are the five research areas described in the following article.

We believe these research areas will ensure a coherent, rigorous and innovative foundation for systemic and sustained transformation of our engineering education system. Thus, better preparing our graduates to adapt to the rapidly evolving technical, social, and global environment and to be leaders in addressing societal challenges.

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# The Research Agenda for the New Discipline of Engineering Education

## I. Introduction

Rapid changes in the worldwide engineering enterprise are creating a compelling rationale for us to rethink how we should educate future generations of engineers [1–4]. According to *The Engineer of 2020* [5], tomorrow's graduate will need to collaboratively contribute expertise across multiple perspectives in an emerging global economy that is fueled by rapid innovation and marked by an astonishing pace of technological breakthroughs. Deteriorating urban infrastructures, environmental degradation, and the need to provide housing, food, water, and health care for eight billion people will challenge the analytical skills and creativity of engineers. From a U.S. perspective, a continuing decline in interest by American youths in engineering, a shrinking capacity for technological innovation, and an engineering research infrastructure in distress are early warning signs that the nation's prosperity and security are at stake if we fail to take action. Our leadership and capacity for innovation are destined to erode unless current trends are reversed [6–8].

Meeting these and future challenges requires a transformational change rather than incremental improvements in how we recruit and educate engineering students. Business, academic, and government leaders from across the engineering enterprise have repeatedly remarked that systematic research of how we educate engineers must be the path by which we transition from episodic cycles of educational reforms and move to continuous, long-lasting improvements in our education system[1]. Research in engineering education must become the engine that drives change to improve the technical fluency of students and teachers, increase interest in engineering and awareness of the social impact of the engineering profession, increase diversity in the engineering student body, and increase the U.S. contribution to the global engineering workforce. Such research will provide the principles, methodologies, and educational practices upon which to continuously build innovative curricula that lead contemporary engineering practice and meet the needs of the nation and the world. Ultimately, we assert that a rigorous research-based approach to our educational system, similar to the way in which research is performed and used in the traditional engineering disciplines, it will allow us to be more competitive on the global stage and position us to begin addressing national and global grand challenges.

The Engineering Education Research Colloquies (EERC) were designed with this transformational change in mind [9]. Representing a collaborative effort of more than 70 engineering, science, and mathematics educators and researchers, learning scientists, and practitioners, EERC participants worked to address the challenges and future needs of engineering education. This report presents five research areas that will collectively serve as the foundation for the new discipline of Engineering Education. We envision a synergistic research agenda that will profoundly enhance the U.S. capacity to educate future engineers by shaping our understanding of: what content (knowledge and skills in context) future engineers must possess; how said content is being learned; and how learning of the content should be assessed. This research in turn will inform how the content should be taught as well as how future leaning environments should be designed. Finally, understanding these fundamental areas will facilitate our ability to attract, engage and retain the diverse cadre of human talent needed to be a more inclusive and prosperous world community of engineers.

## II. Research Areas

The five research areas for the new discipline of Engineering Education consist of one or more interrelated strands of research that can be investigated independently or integrated with other areas of inquiry. The research areas include:

- Engineering Epistemologies
- Engineering Learning Mechanisms
- Engineering Learning Systems
- Engineering Diversity and Inclusiveness
- Engineering Assessment

**Area 1—Engineering Epistemologies:** *Research on what constitutes engineering thinking and knowledge within social contexts now and into the future.*

Engineering education prepares students to affect the world of tomorrow, thus engineering education researchers must explore what the engineer of tomorrow will need to know. Students and employers alike expect a high degree of synergy between what is learned in classroom and what is needed in the field for successful practice. Describing and defining the nature of engineering work as a professional enterprise and articulating the roles of engineers in that work are critical components of creating this synergy. Although there is an implicit understanding of the essence of engineering thinking and knowing, as evidenced both in our current

[1]As exemplified in recent editorials in the *Journal of Engineering Education* (Kerns, 2005; Gabriele, 2005; Haghighi, 2005; Fortenberry, 2006; Streveler and Smith, 2006) and in the Special Issue devoted to the State of the Art and Science of Engineering Education Research (Lohmann, 2005; Felder, Sheppard and Smith, 2005). Also see "Envisioning a 21st Century Science and Engineering Workforce for the United States", A report to the Government-University-Industry Research Roundtable, The National Academies Press, 2003.

educational system and in reports seeking to facilitate improvements in engineering education, the profession needs research that will help characterize the nature of engineering knowledge (i.e., its technical, social, and ethical aspects) and ways of engineering thinking that are essential for identifying and solving technical problems within dynamic and multidisciplinary environments. The ever-increasing pace of change in the engineering enterprise makes characterizing engineering a particularly challenging yet essential step to developing a meaningful understanding of the nature and long-term needs of engineering education. Research that attends to the historical, contextual, and philosophical dimensions underlying the engineering profession is important in guiding such efforts.

Research is needed along four strands of inquiry: 1) What knowledge, skills, processes, values, and attitudes characterize engineering as a unique field, and what are the mechanisms by which these defining elements change over time? 2) How do elements such as innovation, critical thinking, systems thinking, biology, mathematics, physical sciences, engineering sciences, problem solving, design, analysis, judgment, and communication relate to each other to characterize the core of engineering as a profession? 3) What is the source of these core elements, and how are they shaped? Is engineering best characterized by the people it serves, the problems it addresses, the knowledge used to address problems, the methods by which knowledge is applied, or its social relevancy or impact? 4) What is the connection between what students are taught and how (and if) they practice engineering once they graduate? Where *do* and where *should* engineers learn core elements, and who is involved in these decisions?

**Area 2—Engineering Learning Mechanisms:** *Research on engineering learners' developing knowledge and competencies in context.*

Experienced engineers and scientists from around the world are accelerating the pace of discovery and transformation of this new knowledge into viable products, processes and services. However, maintaining this growth potential coupled with the retirement of expertise from technical disciplines will require a transformational change in how we prepare our learners across all ages. Therefore, fundamental research that describes the knowledge, skills, and attitudes learners' bring to their engineering education that influences what they learn as well as how students develop the ability to learn, think, innovate, and problem solve like an engineer will challenge current assumptions about how we teach and assess for understanding.

Learning to engineer will require three major strands of inquiry that centers on understanding: 1) learners acquisition, comprehension, and synthesis of domain specific knowledge to achieve contextual goals; 2) the learning progressions of learners and their educational experiences that develop this knowledge and identity necessary to be an engineer; and 3) the variance of knowledge, skills, and attitudes of a diverse population of learners. For example, the first area addresses questions such as: What principle characteristics describe how learners acquire, comprehend, and synthesize domain specific knowledge? What barriers impede learners' ability to learn with understanding (e.g. misconceptions, mathematical literacy, attitudes)? The second area of inquiry centers on questions like: How do learners progress from naïve conceptions and partial understandings to richer knowledge and skills that facilitate innovative thinking? What learning progressions of content, concepts, skills, and attitudes develop competent and motivated engineers? The third area of inquiry considers questions like: What knowledge, skills, and attitudes do learners bring to their engineering education that influences what (and how) they learn? What factors define how learners engage in engineering related activities and their willingness to persist in these activities? Knowledge from each of these strands of research will inform how we can transform our educational approach to a method that invites more students into the engineering community and better prepares them for the rising challenges of increasing new knowledge and information, global competition and growing needs of society.

**Area 3—Engineering Learning Systems:** *Research on the instructional culture, institutional infrastructure, and epistemology of engineering educators.*

The rapid pace of innovation and the need for engineers to continually learn about and exploit the capabilities of new discoveries will require a transformational change in how we educate our engineering students. This implies creating formal or informal learning experiences in a variety of settings (e.g., classrooms, laboratories, exhibits, synchronous and asynchronous on-line activities) that are more motivating, more engaging, and address the needs of a diverse group of learners. Currently, engineering educators turn to general education literature, most of which comes from the K-12 setting, to inform their understanding of teaching and learning. Research from the K-12 literature provides useful insights related to learning in disciplines such as physics and mathematics; however, research that explores the unique elements of engineering that extends learners knowledge would be invaluable. Therefore, research is needed to inform collegiate instruction and the instructional culture, institutional infrastructure, and the practices and epistemology of engineering educators. Such research would promote synergy with research on how engineering students learn and the nature of engineering knowledge. This research area is driven by three fundamental questions: 1) What instructional theories can guide the engineering education community in making decisions about the education system (i.e., curriculum, courses, organizational structure, and pedagogical practices) that are most effective for engineering learners that are at different educational and professional levels? 2) How can we characterize the engineering teaching culture (i.e., social interactions, beliefs about teaching and learning, and the growth of communities of educators) in order to inform the development of current and future engineering educators for teaching practice? 3) What systems-level theories can guide the sustainability and continual improvement of engineering education systems in diverse instructional contexts and across scales? This would include examining new organizational schemas for departments and colleges, as well as exploring the interdisciplinary integration of subject matter such as humanities, social sciences, natural sciences, and engineering.

Answers to these questions can lead to more effective and efficient engineering instruction that will 1) better prepare graduates to immediately engage in engineering practice and address the complexities of diverse and global work environments; 2) ground instruction in a theory of practice and build upon a robust base of engineering education research; 3) better prepare faculty to enter the teaching profession and make a significant impact on student learning; and 4) produce educational infrastructures that create and disseminate educational innovations.

**Area 4—Engineering Diversity and Inclusiveness:** *Research on how diverse human talents contribute solutions to the social and global challenges and relevance of our profession.*

Engineering and society are inter-related—each one shapes the other. It is imperative to understand the influences of diverse human talents on society in order to encourage innovation, creativity, and global understanding to achieve a more equitable, inclusive, and prosperous world community. Creating a workforce that is capable of thinking and working across diverse perspectives is imperative to the future of engineering. To achieve this goal, we must characterize diversity, build communities that value diversity, and develop programs and initiatives to leverage diversity.

This research area examines how diverse perspectives, experiences, and ideas contribute to engineering processes and products. We need to learn how to measure diversity and its impact in order to understand the role diversity plays in advancing solutions, influencing society, and contributing to innovation, critical thinking, creativity, teamwork, entrepreneurship, leadership, and global competencies. Ultimately, research must uncover the processes and environments that promote understanding of how we can achieve and sustain a diverse engineering community. Engineering education must be shaped by research that answers questions such as: What are the best practices for faculty development related to diversity? How can the design of learning environments and curricula capitalize on diverse learning styles? How can effective mechanisms be established to help students choose pathways to align with diverse cultural and background experiences? How does diversity within the faculty impact teaching and learning? How is a body of shared understanding created? What is learned from other disciplines, and how is that experience effectively transferred into engineering?

**Area 5—Engineering Assessment:** *Research on, and the development of, assessment methods, instruments, and metrics to inform engineering education practice and learning.*

Assessment research is a key element to the continuous improvement of engineering education. Information gained through valid and reliable assessment provides critical feedback to the educational system about the 'state' of engineering as a profession, student engagement and learning, and teaching methods and systems. Future engineering educational innovations require the development or adoption of methodologies and instruments specific to engineering domain knowledge. This development will be influenced by research methodological approaches (both traditional and emergent), cultural drivers and barriers for assessment, and faculty epistemological perspectives.

The development, adaptation, and transfer of methods, instruments, and metrics into the engineering education system require research on those methodological approaches conducive to the engineering educational environment, such as learning processes, different kinds of domain knowledge, socio-cultural factors, and teaching pedagogies. Assessment research must investigate, for example, elements of psychometric properties and aspects of triangulation associated with designing assessment instruments and methodological practices that may be unique to engineering. Research is also needed on the value systems and effective models for change of institutions and faculty. For example: What deters or engages faculty in assessment? What are extrinsic and intrinsic motivators for faculty to engage in assessment? How does assessment fit into the value system of the institution? What are the implications of using assessment to impact or inform change? and What are effective models for building communities of diverse researchers for developing effective assessment? Ultimately, we need to understand the body of knowledge needed by engineering educators to develop, apply, and evaluate assessment methods and tools as well as define the training necessary to accomplish this goal.

## III. A Call to the Nation

Our understanding of how to educate an engineer is becoming more challenging and sophisticated. Our goal for developing the five research areas has been to build from our collective knowledge to provide synergy and a roadmap for organizing our efforts for educating engineers for the dynamic world of engineering practice. Therefore, we call for collaboration between academia, industry, and government to provide the necessary leadership that will help this initiative become a reality. Our nation needs to make the critical research investments that will transform today's educational system into the preeminent paradigm for engineering education and ensure that the U.S. maintains its leadership role in addressing the global challenges of the future.

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