Purdue University School of Engineering Education

RESEARCH 2012 2014

TACKLE THE BIG QUESTIONS

How do people know they have learned (to be engineers, design engineers, change agents, etc)?

Why are some concepts so difficult to learn?

How much of the behavior we observe in engineering students is because students are noninstructive? How much is influenced by the university, by engineering and by the department?

Matthew Uncar

What do engineers keep and share as they learn?

How can we improve the ability of engineers to work in cross-disciplinary communities?

Anna Simon Schaller

How do we best prepare engineers for their real-world work?

Owen K. Hoff

If students are given hands-on learning experiences, will they learn more effectively than if they are given just books and homework?

Why does community involvement in the learning environment impact learning?

Bridget McPhee

What does research say about teamwork, communication, design, and leadership?
Purdue’s pioneering School of Engineering Education is a vibrant community of scholars who are radically rethinking the boundaries of engineering and re-imagining engineering education, in the broadest sense, to meet the challenges of the future. We seek to transform engineering education based on research and scholarship. This transformation begins when we challenge the unstated assumptions underpinning traditional engineering education: that “business as usual” will get us to where we need to be.

Our research is about understanding knowledge construction and sharing and community membership processes in relation to engineering across all life stages, from pre-kindergarten through the college years and over a career. The motivating research questions arise from diverse settings, where learning about engineering or learning to engineer takes place. In turn, our research findings are helping shape improved educational practices, both formal and informal. Thus educational research and innovative educational practices form a virtuous, interdependent cycle.

I invite you to explore the diverse scholarly interests of our faculty members. They are passionate, imaginative individuals driven by curiosity and a shared sense of mission. Many are thought leaders in their specialty, and collectively their research has had a significant influence on the national and global dialogue on reforming engineering education. I hope you find something that piques your interest.

David F. Radcliffe
Kamyar Haghighi Head,
School of Engineering Education
Epistemology Professor of Engineering Education

based on
Jamieson & Lohmann (2009)
ROBIN S. ADAMS + How do you know you’ve learned?; cross-disciplinary ways of thinking, acting, and being; engineering design learning trajectories and education for innovation; how does engineering education transformation happen?

SEAN P. BROPHY + Thinking about complex systems; transferring knowledge to new contexts; designing effective learning environments

CORDELIA M. BROWN + Assessment of engineering learning; recruitment and retention initiatives in STEM disciplines

MONICA E. CARDELLA + Understanding the relationship between design and mathematics; informal learning environments; assessment instruments for measuring engineering thinking

MONICA F. COX + Career preparation for doctoral engineering students; assessing graduate teaching assistants; developing leadership, change, and synthesis attributes among engineering undergraduates; broadening participation of underrepresented populations in STEM

HEIDI A. DIEFES-DUX + Student learning through mathematical modeling activities; professional development of elementary school teachers

DALE A. HARRIS + Online education and blended learning environments; globalization and engineering

MORGAN M. HYNES + Engaging K-12 learners in engineering for and with people; engineering and design in K-12 settings; how teachers and students conceptualize engineering and design

BRENT K. JESIEK + Global engineering; capacity building and analytics in engineering education research

KRISHNA P.C. MADHAVAN + Personalizing and assessing engineering cyber-environments; capacity building in engineering education research

JOYCE B. MAIN + Access to cooperative education programs; career pathways for science and engineering doctorates

TAMARA J. MOORE + Defining quality K-12 engineering education; integrating STEM disciplines in the learning process; effective STEM instructional and learning practices in learning environments; providing quality teacher and professional development programs that use curricular innovations

WILLIAM C. OAKES + Service learning and design in engineering education

MATTHEW W. OHLAND + Student pathways, success, and institutional policy; supporting the use of teams in the classroom

ALICE L. PAWLEY + Diversity in STEM education; assessing sustainability knowledge in undergraduate engineers

MARY K. PILOTTE + Industrial research activity; bringing authentic engineering practices to the classroom; communication with industry

SENAY PURZER + Assessing innovation and creativity; assessing teamwork, argumentation, and collaborative decision-making; assessing critical thinking and information literacy skills; preschool-12 engineering education

DAVID F. RADCLIFFE + Engineering design and practice research; engineering education systems and communities; learning environments; engineering futures

KARL A. SMITH + Discipline-based education research and innovation; national capacity building in engineering education research and innovation; international capacity building in engineering education research and innovation

RUTH A. STREVELER + Difficult concepts in science and engineering; helping engineering faculty learn to conduct engineering education research

PHILLIP C. WANKAT + Improving teaching; trends in engineering education

INSPIRE + Institute for P-12 Engineering Research and Learning

GRADUATE PROGRAM

SCHOOL OF ENGINEERING EDUCATION: PAST, PRESENT & FUTURE

SCHOOL OF ENGINEERING EDUCATION: STRATEGIC PLAN
How do you know you’ve learned? → Answering this question requires a “language of learning”—a way of talking about what it means to know, be able to do, or be as a professional—and an understanding of how and why this changes over time and through experiences as a learning trajectory. A language of learning helps learners self-assess their own progress, educators design and assess learning experiences, and leaders take action and shape the future of engineering education and engineering as a profession. Dr. Adams’ research seeks to empirically develop languages for learning in areas central to the practice of engineering—cross-disciplinarity and design—and the practice of engineering education. Her group, XRoads, conducts research at the “crossroads” where different perspectives connect, collide, and catalyze new ways of thinking.

Cross-disciplinary ways of thinking, acting, and being → Every day, engineers are confronted with complex and ill-structured challenges that cannot be addressed through a single lens or mindset. Grand “human” challenges require “cross-disciplinary” approaches for thinking, working, and innovating across differences (cultures, disciplines, and lived experiences). While multi-, inter-, and even transdisciplinarity are widely endorsed as critical engineering education goals, our understanding of a language of cross-disciplinary learning is very limited. What is it you learn? How? How would you know if you learned or could apply what you learned to new situations? How does this become a part of who you are and how you approach complex human-social-technical-environmental problems?

Dr. Adams’ research seeks to build theories about learning and becoming “cross-disciplinary” in multiple contexts: engineering, design, cancer research (epigenomics), and engineering education. Her CAREER grant, a three-year longitudinal study, investigates how and why people become effective cross-disciplinary practitioners, drawing on critical incident, photo elicitation, and narrative methods to make visible what undergraduates, graduates, faculty and practicing engineers come to understand through their cross-disciplinary experiences. Dr. Adams has developed frameworks of cross-disciplinary learning (see figure), tools to assess cross-disciplinary problem formulation and collaboration capabilities, and novel methods for investigating how and what people learn through their experiences, and she is collaborating with faculty to form a “Cross-disciplinary Commons.”
to share approaches to cross-disciplinary teaching, learn from each other, and transfer new ideas for use in their own classrooms.

**Engineering design learning trajectories and education for innovation**  
Dr. Adams has conducted in-depth studies of how freshman and senior engineers compare to practicing professional engineers that illustrate critical differences in the use of iterative design strategies, breadth and depth in framing and understanding the problem, and awareness of ambiguity and uncertainty. She integrates this work with research in diverse disciplines (such as engineering, architecture, product design, visual and performing arts, and computer science) to help create a language of design learning that characterizes learning progressions in what designers know, what they are able to do, and how they see themselves as design professionals. This research has been used to guide approaches to design curriculum (from P-12 to postgraduate as well as within and across disciplines) and professional development of design educators, to develop tools to measure changes in design learning over time, and to create the graduate-level course “Design Cognition and Learning.”

**How does engineering education transformation happen?**  
Drawing on cross-disciplinary and complex-systems methods, Dr. Adams seeks to both catalyze change and understand the process of engineering education transformation. She has developed novel ways to bring research “into the classroom,” such as using storytelling with engineering educators to build communities of practice and translating tools used for research into educational strategies that help learners talk about learning in ways that support reflective practice and identity development. She also uses multiple-perspective methodologies to critique and open up new ways of thinking about the aims and process of engineering education. In the course “History and Philosophy of Engineering Education,” she draws on philosophy and history to challenge and transform ways of thinking about engineering knowing and what it means to prepare engineers for the profession. Dr. Adams also uses her “language of learning” lens to study the process of engineering education transformation. She draws from multiple perspectives to investigate how engineering educators link their own work as researchers to their work as educators, how engineering faculty experience shifts in thinking around curriculum design, and how successful “changemakers” understand and talk about the process of educational transformation (their “change knowledge”) and themselves as change agents.

[Funding] NSF DIVISIONS OF UNDERGRADUATE EDUCATION AND OF ENGINEERING EDUCATION AND CENTERS; NATIONAL INSTITUTES OF HEALTH

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**KEY PUBLICATIONS**  
Thinking about complex systems

Engineering students think with models of systems to comprehend and solve complex problems. Dr. Brophy’s research explores how students approach the initial stages of design and problem-solving activities: comprehending a situation and defining the fundamental problem. This work is helping to identify how students generate diagrams and graphs they can use to explain how a device or system works. By posing “what if” questions to these students, his team has learned how well they can use their representations to explain and predict the systems’ performance in various scenarios. Dr. Brophy has been awarded an NSF grant (“Graphical Representations to Assess System Performance,” or GRASP) to explore these fundamental skills and to design a formative assessment system to help students develop this ability to reason with models.

Transferring knowledge to new contexts

Engineers can adapt to novel problem-solving conditions because they have a rich conceptual model that supports their generation of knowledge in unfamiliar contexts. Dr. Brophy leverages his mechanical engineering background to research how learners—including elementary-age, middle-school, and undergraduate students—develop a rich conceptual understanding of physical concepts (e.g., force, conservation of energy) that govern how a system behaves. As a computer scientist, Dr. Brophy has designed devices that help students learn while maximizing their potential to successfully transfer newly learned knowledge to new problem-solving situations. For example, he has collaborated with Dr. Alejandro Strahan, a domain expert in Purdue’s Network for Computational Nanotechnologies (NCN), to identify learning gains with visualizations of how materials behave at the atomic level when external forces are applied at the macro level. Students used a computational model on nanoHUB.org to dynamically generate images of material structures at the atomic scale. The experiment demonstrated students’ ability to transfer knowledge learned in a virtual lab to a novel problem presented on a post-test. Dr. Brophy is integrating these ideas into new projects for the Network of Earthquake Engineering Simulation (NEES), as well as for WaterHUB (for cyber-enabled training, education, and research related to hydrology).

Dr. Sean P. Brophy’s expertise in systems engineering and educational research fuels his work on systems thinking and knowledge transfer used in his designs of effective learning environments and cognitive devices. A recipient of the Journal of Engineering Education’s Wickenden Award for best paper (2007) and an invited participant at the National Academy of Engineering’s 2010 Frontiers of Engineering Education symposium, he has helped lay the foundation for a new paradigm—challenge-based instruction—in engineering education.
Designing effective learning environments | Challenge-based learning environments provide advanced learning experiences critical to the future of engineering education. Dr. Brophy’s published research demonstrates how problems presented in an authentic context help learners acquire knowledge they can transfer into novel situations. Through this work he has been able to contribute to the growing knowledge of methods for designing effective learning environments based on theories of learning and the “How People Learn” framework. Dr. Brophy is working on methods to make the design of learning environments as accessible to other faculty as designing traditional lecture-style courses.

Dr. Brophy continues to develop and research advanced models of problem-based learning with cyber-enabled technologies. Cyber-tools like GRASP and simulation tools engage students in intellectual tasks to better comprehend and evaluate how systems behave. Further, technologies can support team members’ interactions with each other to enhance the productivity of the team. For example, Drs. Brophy and Daniel DeLaurentis received funding to design a challenge-based learning environment for aerospace design using an interactive 3D world. This project has great potential to achieve multiple learning objectives, including knowing conditions for applying content knowledge, developing team design skills, and learning what it means to work as a professional in an engineering context. These same ideas inform the design of a new cyber-learning space called NEESacademy to support the education and outreach needs of the Network for Earthquake Engineering Simulation (NEES), a cooperative agreement with the National Science Foundation.

[funding] NSF DIVISIONS OF UNDERGRADUATE EDUCATION; OF ENGINEERING EDUCATION AND CENTERS; OF CIVIL, MECHANICAL, AND MANUFACTURING INNOVATION; AND OF RESEARCH EXPERIENCES FOR UNDERGRADUATES

How do engineering students think with models to make sense of systems?

KEY PUBLICATIONS

Understanding the relationship between design and mathematics

In work that can inform both undergraduate engineering education as well as the national discussion on mathematics at the K-12 level, Dr. Cardella’s CAREER Award-funded research explores the interplay between mathematical thinking and design thinking—specifically, how undergraduate engineering students’ learning experiences in required mathematics courses impact how they learn engineering design. This is particularly important because design is closely tied to innovation.

Using verbal protocol analysis, which has been employed successfully in past studies to understand design thinking, Dr. Cardella investigates students’ thinking as they work on an engineering design challenge. Students are asked to “think aloud” while working on the challenge, and video recordings of the “think alouds” are examined to determine the types of mathematical thinking activities the students engage in (e.g., how they use mathematical content knowledge, how they employ mathematical problem-solving strategies and mathematical practices like estimation or the use of numerical evidence to form an argument), as well as the design thinking activities the students engage in.

In the data collected for her CAREER-funded project as well as for previous studies of teams of engineering students and practitioners, Dr. Cardella looks for patterns in terms of the types of strategies students use, the point in the process when they begin to use a form of mathematical thinking (such as mathematical content knowledge, mathematical problem-solving practices, mathematical resources, or mathematical practices such as estimation or a mathematical form of argumentation) or when or if they become “fixated” on one design solution and don’t consider other options.

Ultimately, this research provides a foundation for future research related to design and mathematical thinking as well as more-immediate outcomes such as improvements in the teaching of engineering design and mathematical modeling in Purdue’s First-Year Engineering Program.
Informal learning environments

Traditionally, educational research in general and engineering educational research in particular have focused on students’ experiences with learning engineering within curricular structures. However, as students spend the majority of their time in out-of-school settings, it is important (and fruitful) to understand the learning that occurs outside the classroom. This is particularly true for pre-college students, many of whom receive either limited or no engineering instruction in their K-12 classes.

Dr. Cardella has developed key research partnerships with the Science Museum of Minnesota and WGBH (the Boston-based television studio) to investigate how children learn about engineering through play dates with their parents, museum exhibits, television shows, and web resources. As the director of INSPIRE’s newly formed Informal Learning Environments Research team, she mentors a team of graduate students engaged in research on engineering learning in other contexts, such as through storybooks or through other family interactions. This research on understanding the engineering learning that occurs in informal environments provides a foundation for research-informed design of learning experiences for K-12 classrooms, facilitating opportunities for all children to learn about engineering.

Assessment instruments for measuring engineering thinking

There is a need for valid, reliable assessment instruments within the pre-college engineering education research community for measuring engineering thinking. Dr. Cardella has developed research-tested instruments including modified versions of Bailey’s “Design Process Knowledge Task” (measuring elementary students’ and teachers’ understanding of the engineering design process), the “Human-Centered Design Task” (measuring undergraduates’ understanding of human-centered design), and the “Parent Engineering Awareness Survey” (measuring the knowledge, attitudes, and behaviors of parents of K-12 students in respect to engineering and engineering education). She has also studied the effectiveness of different measurement practices. . . .

FUNDING

NSF DIVISIONS OF ENGINEERING EDUCATION AND CENTERS, OF HUMAN RESOURCE DEVELOPMENT, AND OF RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS; THE S.D. BECHTEL JR. FOUNDATION; INSPIRE

Research into how children develop engineering thinking skills in informal environments (like the Children’s Museum of Indianapolis, below) can lead to better learning experiences in K-12 classrooms.

KEY PUBLICATIONS

Student learning through mathematical modeling activities

The engineering workforce of the future must be prepared to address increasingly complex and ambiguous problems, yet effectively teaching open-ended problem-solving has been a challenge for engineering educators. Research in mathematical modeling activities, specifically model-eliciting activities (MEAs), aims to develop effective, transferable student competencies in problem-solving and creativity, as well as prompt more-effective learning and retention of important concepts, identify students’ misconceptions, and nurture engineering habits of mind.

MEAs are authentic, open-ended, team-oriented problems set in engineering contexts that require, in the case of this research, first-year student teams to create generalizable mathematical models for direct users. Originally created to observe the development of student problem-solving competencies and the growth of mathematical cognition, MEAs have been increasingly documented as a method to help students become better problem solvers, as well as a tool to help both instructors and researchers better design situations to engage learners in productive mathematical thinking.

Dr. Diefes-Dux’s work in this area is highly tied to actual classroom implementation. Two to four MEAs have been implemented and studied each Fall and Spring semester since Fall 2002 in a first-year engineering course with enrollments of up to 2,000 students. Data is collected in situ, with all the complications that characterize classroom teaching and learning. What is learned in one implementation cycle is fed directly into the next for continuous and documented improvement. Dr. Diefes-Dux’s research group constantly (re)designs MEA instruction, instructor training, and MEA implementation strategies while collecting and analyzing data around each implementation and disseminating results.

Further research concerns the development of pedagogical approaches for providing formative feedback from peers and teaching assistants. The latter is a step toward growing a community of engineering educators who are better able to teach open-ended complex problems. Principles and guidelines for providing effective feedback will greatly facilitate the dissemination of models and modeling pedagogies to other educational settings.

**Professional development of elementary school teachers** → Early exposure to engineering principles may increase students’ interest in STEM fields. Through Purdue’s Institute for P-12 Engineering Research and Learning (INSPIRE), Dr. Diefes-Dux has been involved in research that supports professional development for elementary school teachers, including the development of a learning progression that increases their ability to adopt and refine engineering learning materials for use in second- through fourth-grade classrooms.

One study, which involves about 120 teachers in four cohort groups, seeks to identify the desired set of student knowledge, attitudes, and behaviors as a result of integrating engineering into formal elementary education, and to determine what teacher knowledge, attitudes, and behaviors are necessary for successful and sustained integration of engineering in the elementary classroom.

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**FUNDING** NSF DIVISIONS OF ENGINEERING EDUCATION AND CENTERS AND OF RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS

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In this MEA, or model-eliciting activity, the consulting firm Federal Security Services requests its engineering team to develop a process for reassembling shredded documents.

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**Memorandum**

To: Engineering Team  
From: Dorothy Belding, Evidence Documents Manager, Federal Security Services  
Re: Shielded Document Recovery Process

Federal Security Services (FSS) is a freelance security consulting firm with numerous governmental contracts. The recent increase in illegal business practices, state and federal government procurement has been contacting us to aid in their investigations. We need to develop a structured method for the recovery of shredded documents that meets a target level accuracy appropriate for our clients. The high profile nature of many of our cases has resulted in more intense scrutiny of our work. We are looking for success and sustained integration of engineering in the elementary classroom.

Due to the recent increase in illegal business practices, state and federal government procurement teams have been contacting us to aid in their investigations. We need to develop a structured method for the recovery of shredded documents that meets a target level accuracy appropriate for our clients. The high profile nature of many of these cases has resulted in more intense scrutiny of our work. We are looking for success and sustained integration of engineering in the elementary classroom.

The picture shown in Figure 1 is a digitized grayscale image. This image happens to be a view seen in an optical microscope. Similar images are currently being stored as scanned document strips. An image is stored as a data file which contains an array of numbers. Each number refers to the grayscale value for each pixel in the grayscale image. The value ranges from 0 for black to 255 for white. In a true black and white image, the grayscale value will range from 0 to 255. The grayscale of each pixel is accessible or not document strips fit together.

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**Key Publications**

Online education and blended learning environments

With the emergence of worldwide communications networks and powerful computer technologies, the number of online learners has increased from nearly none in 1995 to well over 6 million by 2012. Concurrently, the concept of distance learning—once confined to correspondence courses or televised classes—and the delivery of engineering education content online have been redefined.

As an academic and a member of the Sloan Consortium, an organization supported by the Alfred P. Sloan Foundation and committed to making learning available to anyone, anywhere, anytime, Dr. Harris has provided leadership in improving online learning and analyzing implementations that increase the quality of online courses, improve our ability to scale to larger populations, and improve the breadth of coverage of engineering courses. He has participated in two invited papers, assessing (with co-authors) the state of online engineering education, recommending future directions, and highlighting five important components of online learning quality (see figure), thus establishing a fundamental framework for gauging progress in implementing effective online learning opportunities.

Through a Sloan Foundation grant to Purdue’s Engineering Professional Education program, Dr. Harris led an initiative that used blended learning environments to support lifelong learning in Indiana’s manufacturing industry through the Indiana Advanced Manufacturing Education Collaborative. Blended learning environments combine a variety of delivery formats, from face-to-face learning in the classroom to podcasted courses to online courses using tools such as threaded discussion boards.

Refocusing elements of existing courses and programs from face-to-face instructional environments to blended ones resulted in increased access, learning effectiveness, student and faculty satisfaction, and cost-effectiveness. New courses and programs also were developed that addressed industry needs.

Using the blended format is primarily justified, the research demonstrates, for the convenience of the student and/or instructor. Instructors highly valued blended delivery when some face-to-face contact was desired but fully face-to-face delivery was impossible because of logistical restraints. Results suggest that blended courses and programs will fill an important niche complementing Purdue’s other professional education programs.
Dr. Harris combines his academic interests in distance education and in globalization in his graduate-level course “Globalization and Engineering.” Informed by his scholarship in distance education, the course is taught at a distance to employed engineers, almost all of whom have global work experience. In addition to instructor lectures and textbooks, students use asynchronous chat boards, live desktop conferencing, and bidirectional multimedia recording/streaming as part of a fully collaborative learning experience.
Dr. Morgan Hynes does work in promoting the vision that all students have a chance to engage in engineering. His research and outreach work promotes broadening the contexts of engineering and design activities in kindergarten through college settings with the aim of supporting all students—people with diverse backgrounds and interests, especially those underrepresented in engineering—in making personally meaningful connections to engineering. He employs qualitative research methods that allow in-depth study of how students engage—lose themselves in the activity, authentically applying their skills and knowledge—in myriad practices of engineering—developing solutions for and with people to improve the quality of life.

Engaging K-12 learners in engineering for and with people ➔ Dr. Hynes’ research argues for the systematic inclusion of social science and humanities knowledge in engineering for K-12 students, and he has developed illustrative examples of what appealing to the humanistic side of engineering can look like in a classroom setting. These examples are drawn from interactions among student teams from elementary classrooms engaged in engineering activities that demonstrate that engineering is about solving problems for people with teams of people. This work has yielded ideas for research in the education of K-16 students, including work in understanding students’ attitudes, beliefs, and perceptions, particularly among traditionally underrepresented populations, and in exploring how students’ engineering knowledge and practices develop in the context of a people-centered approach to engineering.

Work on integrating engineering and literacy in elementary classrooms has used children’s fiction—typically focusing on problems that characters are facing—as rich context for students to design something for the characters. Research questions include: What do the beginnings of engineering look like in the elementary setting? Does providing a literary context support engineering design practices? The people-centered approach not only portrays engineering as a caring profession but also highlights women and people of color as engineers, in order to broaden perceptions of who can be an engineer.

Engineering and design in K-12 settings ➔ In addressing the problem of preparing Massachusetts middle school mathematics, science, and computer teachers to teach engineering, Dr. Hynes focused his research on the teachers’ instruction and knowledge of the central aspects of the engineering design process (EDP)—the purpose of the EDP; that the EDP is a cyclical, iterative process; and that the EDP fosters communication. The analysis of videotaped classroom observation data revealed that the teachers as a group covered the central ideas regarding the purpose of the EDP and EDP as a cyclical process quite well, but did not cover EDP for fostering communication well. The research explores each central idea and the teachers’ understandings of them as expressed through their explanations in the classroom observations and follow-up interviews.
How teachers and students conceptualize engineering and design

Dr. Hynes’ research aims to understand how students’ and teachers’ engagement in engineering activities influences how they conceptualize the engineering design process. Like any model, an engineering design process is a representation distilled from observing people in action. Dr. Hynes’ approach is first to engage students and teachers in doing engineering, then have them reflect on their work, come up with their own model, and compare that to an existing model. The model becomes more ingrained in students because it derived from their own actions and experiences.

[Funding] NSF DIVISIONS OF RESEARCH ON LEARNING AND UNDERGRADUATE EDUCATION; NASA
Global engineering

Dr. Jesiek’s multifaceted work on global engineering responds to widespread calls to expand and improve global learning opportunities for engineering students and professionals. This research begins with establishing empirically based definitions of global competency for engineers, then turns to question how students and professionals learn to work in diverse, multicultural contexts. Related historical and social studies help students and professionals better understand and interact with different national cultures of engineering, while also contextualizing recent efforts to scale up global engineering education. An important third dimension of this research area involves assessment, including through the use of preexisting survey instruments to study cross-cultural competence and the development and validation of new instruments to measure other dimensions of global competency that are partially or wholly specific to engineering practice.

Specific initiatives include Dr. Jesiek’s work on the International Research and Education in Engineering (IREE) program. Funded by NSF and administered by Purdue University, IREE 2010 sent 58 U.S. undergraduate and graduate engineering students to China for intensive 10-week research experiences in university and industry laboratories. The program also featured extensive pre-departure and on-site orientation activities, a new Engineering Cultures China curriculum, a two-day re-entry meeting, extensive use of the GlobalHUB cybercommunity, and systematic assessment of the program’s outcomes and impacts.

Additional research is under way. For instance, Dr. Jesiek (along with Co-PI Sang Eun Woo) has received NSF support for a project titled “Global Engineering Competency: Definitions, Development Paths, and Situational Assessment.” The primary outcome of this work is a valid and reliable Situational Judgment Test (SJT) that assesses three to four major dimensions of global engineering competency in five distinct regions/contexts. By establishing a means to measure global competence and then widely distributing the resulting instrument, the project will help engineering programs develop courses and curricula that more effectively prepare students for the global realities of engineering practice. This project also represents a cutting-edge effort to utilize situational and scenario-based assessment strategies in engineering education.

Nationally recognized for his research on global engineering, Dr. Brent K. Jesiek draws on expertise in engineering, computing, and the social sciences to improve our understanding of geographic, disciplinary, and historical variations in engineering education and professional practice. The objectives of his teaching and research include enhancing the ability of current and future engineers to work more effectively in an increasingly complex, diverse, interdisciplinary world and supporting the continued development of engineering education as a scholarly community and research field.
Capacity building and analytics in engineering education research | A leader in systematically studying and promoting the development of engineering education as a field, both in the U.S. and abroad, Dr. Jesiek uses social science insights and advanced information technologies to build local and global networks of engineering education researchers, scholars, and practitioners. In reporting on the Advancing Global Capacity for Engineering Education Research initiative, for example, Dr. Jesiek and colleagues analyzed findings from 10 moderated sessions at international engineering education conferences in 2007 and 2008 where participants discussed the current state and future trajectory of engineering education. Using thematic analysis techniques, this work yielded important insights about how engineering education research is related to teaching practice, educational policy, and industry needs—including across regions. These findings in turn informed the creation of a cyclic model to strategically enhance these kinds of relationships.

In a series of related studies, Dr. Jesiek has also pioneered use of “meso-scale” analytic approaches to examine the development and state of engineering education as a field. In addition to looking at research and publication trends in general, this work has investigated levels of activity in specific research areas such as gender and diversity, problem- and project-based learning, and electrical engineering education.

Advancing engineering education scholarship locally and globally via cycles of translation and enrollment

Personalizing and assessing engineering cyber-environments

How can cyber-tools and cyber-environments better enable learning in the engineering and, more broadly, STEM disciplines? In his CAREER Award-related research, Dr. Madhavan combines learning theories (focusing on the student learning experience) and semantic web design (characterizing and creating cyber-environments) to understand educators’ expectations of cyber-tools and cyber-environments as engineering teaching tools and to characterize and optimize how undergraduate learners interact with simulation tools online.

When users interact with an engineering cyber-environment like nanoHUB.org, their patterns of behavior online reflect their goals and levels of expertise (novice to expert) in using that environment. Dr. Madhavan’s work aims to identify user types and their emergent behaviors early on and develop methods for orienting the content, services, and resources within a cyber-environment to allow better learning (and indeed research productivity). In close collaboration with Purdue’s nanoHUB team, his work focuses on developing new techniques known as user flow informatics, wherein the learning environment attempts to understand learners as they flow through the environment. His work is also establishing new paradigms for more fully understanding the research and educational impact of engineering cyber-environments using theoretical frameworks that include more holistic, system-wide analyses of platform data that utilize scientometric, bibliometric, and sociometric indicators.

Capacity building in engineering education research

Scientific problem spaces like engineering and STEM education are prolific and fast-changing. The engineering education and STEM education research communities are producing a tremendous amount of knowledge, but where is it coming from? How is it being diffused? How are communities, organizations, and individuals using knowledge about engineering education practices and research? Only by discovering scientific methods to describe, characterize, and comprehend all of the “dark data” around the problem space of engineering education—that is, data that isn’t systematically organized for search and analysis—can we truly answer these questions. Building on an NSF-funded prototype known as the iKNEER (Interactive Knowledge Networks for Engineering Education Research) platform, Dr. Madhavan’s DIA2 (Deep Insights Anytime, Anywhere)
project will provide a new way for people working on improving STEM research to synthesize knowledge produced through NSF and other federal investments.

DIA2 is designed to allow researchers and NSF program officers to identify, through a web-based knowledge portal, trends in publications and research funding, gaps in current research and funding, and potential collaborators in STEM education. Users will be able to quickly determine who is working in specific areas, their collaborators, funding sources, program officers, research papers, and findings. The system visualizes complex networks of funding and research collaborations with a map created anew for each search. The network maps contain clickable nodes that yield further layers of information leading to a new way for navigating through large and complex datasets.

Combining theories of user-centered design, large-scale data mining, community formation, social network analysis, and interactive visualization, DIA2 promises to accelerate the pace of innovations and their diffusion into widespread use.

**FUNDING**

NSF DIVISIONS OF ENGINEERING EDUCATION AND CENTERS AND OF UNDERGRADUATE EDUCATION

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**KEY PUBLICATIONS**

Access to cooperative education programs → With funding provided by the National Science Foundation, Dr. Main is examining variation in student access and participation in cooperative (co-op) education programs. A co-op in engineering is a partnership between an academic institution and an employer designed to engage students in practical engineering experience through rotations of full-time employment and course study. While much is known about the value of co-op participation, relatively little is known about why there are different rates of participation by race/ethnicity and how recruitment and pre-screening practices influence the diversity of students who participate in co-op programs. The objectives of this research strand are to identify factors that influence student access to cooperative education programs and to determine the educational and employment returns associated with participation. The comprehensive findings can be used to enhance co-op programs and policies to engage a broader range of engineering students to acquire potential academic and employment benefits.

Career pathways for science and engineering doctorates → The goals of this research strand are twofold: (1) to engage students from a broad range of backgrounds and experiences to pursue and complete doctorates in science and engineering (S&E), and (2) to diversify the composition of the engineering professoriate. Using comprehensive survey and longitudinal administrative data from two research-intensive institutions, Dr. Main is investigating factors that influence the graduation probability of S&E doctoral students and their subsequent career trajectories. She is particularly interested in the role of mentorship in academic persistence among women doctoral students. Further, Dr. Main is analyzing data from the National Study of Postsecondary Faculty and the National Science Foundation’s Survey of Doctorate Recipients to elucidate the career patterns of S&E doctorates. Funded by the American Educational Research Association, this research examines how institutional factors, such as the provision of paid parental leave and subsidized childcare, intersect with family formation to influence the career trajectories and progression of S&E doctorates. Findings have the potential to help shape institutional policies to facilitate work-life integration among faculty.

Joyce B. Main

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A Fellow of the 2014 Houston Higher Education and Finance Roundtable and the 2013 National Data Institute with the Association for Institutional Research, Dr. Joyce B. Main conducts research on factors that influence the academic and employment outcomes of science and engineering students. Her research focuses on engagement of students from a broad range of backgrounds, particularly at critical transitions between postsecondary education and career formation. Dr. Main applies her expertise in higher education policy to inform the design of programs and policies to support student academic success, professional development, and attainment of post-graduation employment.
Social Policy and Higher Education Research in Engineering

The SPHERE Laboratory engages in empirical research to advance programs and policies for improving student academic and employment outcomes.

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**KEY PUBLICATIONS**


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Defining quality K-12 engineering education

Dr. Moore’s research has identified characteristics of a quality engineering education at the undergraduate level—a “Framework for Quality K-12 Engineering Education.” This involved an extensive literature review for K-12 engineering and STEM education, and understanding the ways in which teachers and schools implement engineering and engineering design in their classrooms. The framework is designed to be used as a tool for evaluating the degree to which academic standards, curricula, and teaching practices address the important components of a quality K-12 engineering education. Additionally, this framework can be used to inform the development and structure of future K-12 engineering education standards and initiatives.

Integrating STEM disciplines in the learning process

How does engineering and engineering thinking promote learning in the K-12 classroom, as well as in higher-education engineering classrooms? Dr. Moore defines this area of research as STEM integration—the merging of all or some of the content and practices of science, technology, engineering and mathematics in order to deepen and broaden student understanding of STEM disciplines and increase interest in STEM careers. She examines effective practices in STEM teaching and learning through complex problem solving, inquiry-based learning and cooperative learning.

To investigate STEM integration, Dr. Moore’s research is guided by the rich and engaging learning experiences that foster deep content understanding in STEM disciplines for all students. She examines the need for curricula that integrates STEM contexts for teaching disciplinary content in meaningful ways. There also is a focus on the need for new models of teaching, so instructors can learn disciplinary content using STEM contexts that lead to meaningful learning.

Effective STEM instructional and learning practices in learning environments

Most of Dr. Moore’s funded research projects focus on the creation and implementation of engaging and interactive learning experiences for students through curricular innovation. One example of this research is to build upon and extend the framework for mathematical modeling tasks called Model-Eliciting Activities (MEAs), which are case-based, authentic assessments of real-world contexts (e.g., engineering tasks) that require...
teams of students to come to a solution. Similarly focused research involves the PictureSTEM project. This aims at integrating science, technology and mathematics content instruction in meaningful and significant ways for kindergarten through fifth grades. These instructional modules have the potential to transform the way literacy and STEM are taught at the elementary level.

**Providing quality teacher and professional development programs that use curricular innovations**

Understanding student success is dependent on teacher effectiveness, Dr. Moore is working on EngrTEAMS to increase grade 4-8 student learning of science and mathematics concepts. This project is designed to help teachers develop engineering design curricular units for each of the major science topic areas within the Minnesota State Academic Science Standards for use across the United States and beyond. Because the teachers who teach in high-needs schools will develop and implement the curriculum modules, this project will be able to document the learning outcomes of underrepresented populations when presented with curriculum modules.

**Funding**

NSF MATHEMATICS AND SCIENCE PARTNERSHIP PROGRAM; NSF TRANSFORMING UNDERGRADUATE EDUCATION IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (TUES) PROGRAM; NSF CAREER PROGRAM—ENGINEERING EDUCATION AND CENTERS

**Key Publications**

Service learning and design in engineering education

EPICS (www.purdue.edu/epics) is the focus of and often the context for Dr. Oakes’ research. EPICS has three components: EPICS Purdue, EPICS University, and EPICS High. EPICS Purdue comprises the EPICS courses that draw first-year students through seniors from across engineering and across campus (70+ majors). Students engage in the design, development, and delivery of projects that address needs within local and global underserved communities. EPICS University, based at Purdue, works with other universities nationally and internationally to implement EPICS programs at those institutions. Curriculum and assessment materials are developed at Purdue and shared across EPICS programs. EPICS High works nationally and internationally to engage high school students in identifying needs within their own communities and developing designs that use technology to meet these needs. Teachers and engineering mentors are trained by EPICS High to guide the student teams. EPICS High is active in 10 states and seven countries and is engaging a substantially more diverse population than traditional pre-engineering programs while meeting needs of local communities. Thousands of students have participated in EPICS programs nationally and internationally, delivering projects to local communities and affecting countless lives. Dr. Oakes’ research is focused around themes of understanding and enhancing the impact of the university and pre-university programs on students, faculty/teachers, and communities.

DESIGN
How do students learn human-centered design? How can we assess this learning? What is the impact of the service-learning context?

PROFESSIONAL SKILLS
How do students develop professional skills, including cross-disciplinary teaming and leadership, communication, and ethical reasoning? How do we assess these skills? What is the impact of the service-learning context? What is the impact of the cross-disciplinary experience on students within and outside of engineering?

PROFESSIONAL PREPARATION AND PERSONAL IMPACT
How do service-learning experiences such as EPICS prepare students for their professional careers? What impact do these experiences have on graduates (e.g., their career choices, civic engagement, volunteering)?
GLOBAL AND COMMUNITY PERSPECTIVES  How do local and global experiences develop cultural and social awareness? How do these experiences impact student identity, as a person and a professional? What are the differences in local and global service-learning experiences on participants?

COMMUNITY IMPACTS  How do these programs impact communities? How does partnership with EPICS influence views of engineering?

FACULTY AND TEACHER DEVELOPMENT  How can faculty and teachers be equipped and supported to guide diverse EPICS teams, maximizing learning and community impact? How does EPICS impact them, professionally and personally, and their view of engineering?

ENGINEERING PATHWAYS AND DIVERSITY  How does EPICS impact students’ interest, participation, and retention in engineering? What is the impact on populations who have traditionally been underrepresented in engineering?

ENGINEERING PATHWAYS AND DIVERSITY  How does EPICS impact students’ interest, participation, and retention in engineering? What is the impact on populations who have traditionally been underrepresented in engineering?

Purdue EPICS students and faculty pose in front of a new home for Habitat for Humanity, along with the proud homeowner and her son. Funded by Ford Motor Company, the home was designed by the EPICS team to have lower energy costs and was built in BioTown USA (Reynolds, Indiana) using sustainable construction practices to reduce cost and environmental impact.

[KEY PUBLICATIONS]
Dr. Matthew W. Ohland’s research focuses on [1] longitudinal studies of engineering students’ persistence and performance and [2] team formation and team skill measurement, both of which enable data-driven decision-making for engineering faculty and administrators. A two-time recipient of the Journal of Engineering Education’s Wickenden Award for best paper (2009 and 2012) and of the Helen Plants Award for best non-traditional session at the Frontiers in Education conference (2008), Dr. Ohland has made a national impact through his research and his sustained commitment to the development of the field of engineering education.

Student pathways, success, and institutional policy

To study engineering student pathways, Dr. Ohland created the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), which includes up to 20 years’ transcript-level data for nearly one million students at 11 universities—205,980 of them engineering students. Including all undergraduate students in the dataset, not just engineering students, enables important comparisons to understand how students in engineering are different from—and similar to—students in other disciplines and to help institutions identify how various racial and gender groups are performing.

This work has dispelled the long-held belief that engineering has a lower rate of retention than other majors. Retention appears to be low because although more engineering students do persist, those who leave are not replaced because there is little influx into engineering from other disciplines. This finding is changing the conversation around retention in engineering education, pointing to the need to examine recruitment strategies and curricular flexibility to attract more students to engineering before and after they enroll in college.

Further work showed that women enrolling in engineering are as likely to graduate as men. While there is a gender gap, it does not widen during the college years. Dr. Ohland and his research group are also taking a critical look at how success is measured in engineering education, the biases that result when certain measures are used, and the value of using multiple measures. This work is likely to change the standard set of metrics used in measuring the progress of engineering students.

The findings of Dr. Ohland’s longitudinal studies of engineering students have affected both policy and practice in engineering colleges, providing important guidance to faculty, administrators, and directors of women in engineering programs and minority engineering programs.

Supporting the use of teams in the classroom

Dr. Ohland directed the development of the Comprehensive Assessment of Team-Member Effectiveness (CATME, an instrument and web-based tool for peer evaluation) and the Team-Maker (a web-based system for team formation; see https://engineering.purdue.edu/CATME for both).
If faculty assess team effort at all, they commonly use a fixed-allocation, zero-sum-game system—e.g., each member of a team of four has 100 points to allocate, and awarding 25 points to each team member indicates equal effort. Such systems are fraught with inaccuracy: there is social pressure to give equal ratings, and the rating itself focuses on the credit awarded. Other approaches either are too complicated or fail to distinguish the multiple ways that students contribute to team activity. Dr. Ohland’s research demonstrated that the use of behavioral anchors is more efficient and effective.

These tools for managing academic teams are used by more than 1,800 faculty and 90,000 students at 400 institutions around the world, and were recognized with the Premier Award for Excellence in Engineering Education Courseware.

[**Funding**] NSF DIVISIONS OF ENGINEERING EDUCATION AND CENTERS, UNDERGRADUATE EDUCATION, HUMAN RESOURCE DEVELOPMENT, AND RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS

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**Selected Key Findings From the MIDFIELD Database**

| Proportion of students who matriculate in engineering who are still enrolled in engineering in their eighth semester | 57% |
| Proportion of students enrolled in majors other than engineering who, in their eighth semester, had originally matriculated in another major area | 30-65% |
| Proportion of students enrolled in engineering in their eighth semester who had originally matriculated in another major area | 7% |

**ENGINEERING DEMONSTRATES THE HIGHEST RATE OF PERSISTENCE AMONG ALL MAJOR AREAS STUDIED**

**THE ROAD IS NARROW FOR STUDENTS TO MIGRATE INTO ENGINEERING FROM OTHER MAJORS**

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**Usage of the CATME Tool, 2005-2012**

- The system has had 94,970 unique student users through April 2012.
- Faculty and staff were involved from 0 to 2200 institutions.

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**KEY PUBLICATIONS**


Diversity in STEM education

AT THE UNDERGRADUATE LEVEL Over the last three decades, educators in engineering have made massive efforts to increase the numbers of women and people of color in engineering undergraduate programs. While numbers have improved, they have stalled at dispiritingly low levels.

Through her NSF CAREER Award-sponsored research, Dr. Pawley heads a project that asks, How do underrepresented undergraduate engineering students describe their interactions with educational institutions through personal narratives? What institutional factors do these narratives reveal that affect the educational persistence and success of white women and students of color in undergraduate engineering educational institutions?

The narratives will be analyzed both deductively (informed by sociological theories of institutional structure and critical intersectional theories of gender and race) and inductively (deploying feminist and decolonizing methodological strategies and theories) to propose a new theoretical framework of “gendered” and “raced” institutions in the context of engineering education that can be incorporated into researchers’ and practitioners’ ways of understanding “underrepresentation.”

The broader significance and importance of this project will be to provide new insights into the perplexing and persistent problem of low representation of some groups in engineering degree programs and, it is hoped, to inform policy decisions within engineering schools and potentially at other higher education administrative levels as well.

AT THE FACULTY LEVEL In other diversity-related research initiatives, Dr. Pawley co-created the Purdue Center for Faculty Success (PCFS), which provides targeted research, programs and university-level coordination to increase the number of minority women in STEM faculty positions, improve the success of all women STEM faculty, and engage all faculty in transforming the institution to be more inclusive of women and people of color.
Dr. Pawley’s long-term research goals in this project are to understand the key factors that impact the recruitment and success of women, especially minority women, in STEM faculty positions at Purdue and to inform the implementation of effective institutional policies and procedures that can improve women faculty members’ opportunities for academic advancement.

The research team conducts two main studies. The Academic Career Pathways study works to determine the extent to which women’s career pathways into and through the academic levels in STEM disciplines at Purdue are modeled by pipeline or chilly climate ideas and vary by ethnicity, and how we might conceive of new studies. The Institutional Ethnography study explores faculty members’ lived experiences of two key policies: the promotion and tenure policy that varies by college, and the parental leave policy that started at the same time as the grant. This research uses intersectional theory to look at race and gender together, and initiates institutional change through policy recommendations.

Assessing sustainability knowledge in undergraduate engineers

This research aims to develop a conceptual framework for assessing sustainability knowledge gained by undergraduate engineering students and to explore elements of a sustainability concept inventory. The goal is to help faculty learn how to better prepare students to work as engineers in and for a world impacted by climate change.

[FUNDING] NSF DIVISIONS OF HUMAN RESOURCE DEVELOPMENT AND OF ENGINEERING EDUCATION AND CENTERS

Co-edited by Dr. Pawley, Engineering and Social Justice: In the University and Beyond invites scholars to think and teach in new ways that acknowledge the social, as well as technical, impact of engineering on our world and that open possibilities for social justice movements to help shape engineering and technology.

KEY PUBLICATIONS

Industrial research activity — As demographics shift within the industrial workplace due to increasing Baby Boomer retirements, the critical concern of engineering knowledge capital retention grows. Dr. Pilotte’s research explores topics around engineering culture, including engineering communication behaviors and norms. In particular, identifying potential areas of difference and/or similarity across aspects of diversity (ethnicity, gender, engineering discipline, industry sector, position title) for practicing engineers within industry. This was a first step in discovering areas of potential to maximize knowledge sharing and transfer within engineering workgroups. In similar research, she focuses on differentiated aspects of the engineering work culture.

Bringing authentic engineering practices to the classroom — Relative to the School of Engineering Education’s desire to increase industrial contact, Dr. Pilotte is creating engaging student learning through opportunities for “real-life, in-context practice-based problem solving.” Exposing students to the uncertainties and difficulties they will face in their career as an engineer helps them develop the competencies, positive attitude and perseverance to see any engineering problem to completion. She hopes the relationships and data sets cultivated inspire future practice-oriented study extensions, expanded analysis, and opportunities for even greater industrial engagement.

Related to industrial contexts, as faculty of practice, significant effort has been placed on identifying and idealizing industry-based projects that can be scoped and appropriately positioned into First-Year Engineering (FYE) and Multidisciplinary Engineering (MDE) classrooms. In that vein, she is examining sections of Purdue’s FYE courses, to assess students’ perceived value of industry partner contact.

Communication with industry — Dr. Pilotte understands the importance of sharing information with industry, so that executives may put in place policies that enhance the quality of the engineering profession with and among employees. Likewise, reaching out to industry allows them to give input and become an active stakeholder in engineering education. She produces and distributes “Industry Slicks”—brief documents—that explain her research and why the topic and findings matter to those in the boardroom and how it may improve their operation.

Mary K. Pilotte

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Dr. Mary K. Pilotte describes herself as an “intra-preneurial agent of change” with more than 20 years’ experience in engineering, manufacturing and operations excellence. She has held a variety of industrial leadership roles, including manufacturing plant management, design engineering manager for new product and process development, and director of interdisciplinary integration teams for strategic mergers and acquisitions. Dr. Pilotte’s goal is to have students gain real-life, practical experience in the classroom by solving open-ended problems of industrial concerns, similar to what they may face when working in engineering practice.

Dr. Mary K. Pilotte understands the importance of sharing information with industry, so that executives may put in place policies that enhance the quality of the engineering profession with and among employees. Likewise, reaching out to industry allows them to give input and become an active stakeholder in engineering education. She produces and distributes “Industry Slicks”—brief documents—that explain her research and why the topic and findings matter to those in the boardroom and how it may improve their operation.

“I’m interested in engaging industrial firms in order to bring real-life, practical experience to our students.”
Assessing innovation and creativity → This much-needed and urgent area of research—the subject of Dr. Purzer’s NSF CAREER Award—has broad impact for the education of engineering students and the economic development of societies.

Engineers are expected to produce better, more efficient, and more affordable designs than the designs of previous generations. This project seeks to develop ways to measure the innovation skills of engineering students and use these findings to design engineering degree programs that produce more innovative graduates.

Dr. Purzer is [1] investigating how engineering students define innovation, understand the innovation process, and engage in innovation; [2] developing an understanding of possible gender and cultural differences in students’ approaches to innovation; [3] defining innovation in light of literature and research findings; and [4] developing assessments for classroom use in both college and pre-college settings.

Assessing teamwork, argumentation, and collaborative decision-making → Engineering is a social activity. Hence, the study of discourse, collaboration, and argumentation is an essential component of engineering education research. In her dissertation, Dr. Purzer investigated a first-year design classroom and the relationship between team interactions and individual student learning. In this project, she employed mixed-method approaches to gain a deep understanding of an engineering design classroom environment, using hours of video-recorded student discussions and classroom activities.

Her recent projects examine argumentation among engineering students and the relationship between team collaboration methods and the quality of collaborative decisions.

Assessing critical thinking and information literacy skills → Skills, tools, and methods used in engineering are constantly changing and evolving. Engineering students thus have to seek information and resources beyond what they gain through coursework on their own. Dr. Purzer’s research in the assessment of critical thinking and information literacy skills led to the
One discovery activity in this project is the development of grade-appropriate, standards- and engineering design-based science lessons for grade 3-6 students.

**Preschool-12 engineering education**

Improving preschool-12 (pre-college) engineering education is critical to recruiting more diverse and more able engineering students. As director of the INSPIRE Assessment Center (INSPIRE is Purdue’s Institute for P-12 Engineering Research and Learning), Dr. Purzer develops assessment tools, including creativity assessments for design projects used in elementary classrooms.

She also leads an initiative, the “INSPIRE Assessment Center for STEM Literacy” project, that aims to widen and ease the dissemination of valid and reliable assessment instruments for measuring various constructs related to pre-college engineering. Through these and other efforts, the center serves as a platform for collaboration and supports the growing community of pre-college engineering education researchers, outreach developers, and P-12 teachers. Dr. Purzer is also working closely with Purdue’s Women in Engineering Program to enhance program evaluation techniques.

Along with her involvement in INSPIRE, Dr. Purzer is a STEM faculty coordinator on a large-scale, multi-year NSF Math Science Targeted Partnership grant (Science Learning through Engineering Design, or SLED) that examines the purposeful integration of engineering design-based instruction in the elementary school (grades 3-6) setting. One discovery activity in this project is the development of grade-appropriate, standards- and engineering design-based science lessons for grade 3-6 students.
Engineering design and practice research

Intrigued by the related questions of *What is the nature of engineering practice, in particular engineering design?* and *What does it take to prepare for it?*, Dr. Radcliffe initiated two interdisciplinary research groups to study engineers in situ. These groups, the Engineering Practice Research Group and later the Catalyst Research Centre for Society and Technology, comprised researchers from engineering design, industrial anthropology, learning sciences, and information sciences. The research involved the development of a new sociotechnical research framework that drew upon diverse research methodologies and methods (including ethnography and phenomenography) to study engineering teams in their daily practice by researchers embedded in the workplace, often for extended periods. Much of this research was conducted as part of a series of strategic learning partnerships with engineering firms across aerospace, construction, and mining industries in Australia as well as new product development in SMEs (small and medium enterprises) and rehabilitation engineering in clinical settings. The current focus of this work is on professional competencies and engineering epistemologies.

Engineering education systems and communities

Dr. Radcliffe also undertakes research and policy development and implementation focused on engineering education transformation. This began when he prepared the first draft of “Changing the Culture: Engineering Education into the Future,” the report that changed the accreditation of the engineering programs in Australia in the 1990s into outcomes-based assessment. The motivating question is, *How can we bring about systemic change in lifelong engineering education sufficient to meet the emerging challenges facing societies globally?*

Dr. Radcliffe created the Advanced Engineering Capability Network in Australia to identify success factors for industry-education-community partnerships and developed the Capability Strategy Matrix (CSM) as an analytical framework to explore the many different types of capacity-building programs by aligning educational initiatives in K-12 with university engineering programs and a wide variety of continuing professional development initiatives. Current research explores the transition of the engineering education research community from loose networks of relatively isolated scholars to the formation of academic units.
Learning environments

Dr. Radcliffe has pursued a line of research and innovation over the past 15 years driven by such questions as, *How does the design of formal and informal, physical and virtual learning environments influence pedagogy? How do cultural and historical perspectives, national and disciplinary, influence the design of learning places? What can be learned from innovative design and engineering workplaces for the design of collaborative learning places?* The interdisciplinary Next-Generation Learning Spaces project produced the Pedagogy-Space-Technology framework for creating “fit for purpose” learning environments. The current focus of this research is on comparative analysis of the development of learning environments in different disciplines and different national settings and cultural traditions globally.

Engineering futures

These research themes are part of a broader scholarly interest in understanding the major eras of engineering education past and present in relation to trends in industry and engineering practice over the past century or so. This historical perspective sheds light on how we can educate engineers to meet pressing global challenges—climate change, water, energy, food, housing, transport, urbanization, sustainability—in the context of major geopolitical and demographic shifts.

FUNDING NSF OFFICE OF CYBERINFRASTRUCTURE; AUSTRALIAN RESEARCH COUNCIL; CARRICK INSTITUTE; INDUSTRY

Discipline-based education research and innovation

Dr. Smith is participating in the National Research Council’s consensus study on discipline-based education research (DBER), one of two experts invited to represent engineering in an initiative that also encompasses physics, biology, the geosciences, chemistry, and astronomy. DBER combines knowledge of teaching and learning with deep knowledge of discipline-specific science content, and describes the discipline-specific difficulties learners face and the specialized intellectual and instructional resources that can facilitate student understanding.

Dr. Smith and colleagues have synthesized empirical research on undergraduate teaching and learning in the STEM disciplines; explored the extent to which that research currently influences undergraduate instruction; and identified the intellectual and material resources required to further develop DBER. Post-secondary institutions will be able to use the resulting report—which marks a major step in advancing the disciplinary-based education research agenda—for guidance in instruction and assessment to improve student learning, in bringing greater attention to student mastery (or conceptual understanding) and attrition issues that are related to quality of instruction, and in increasing interest and research activity in DBER.

National capacity building in engineering education research and innovation

As a member of the planning committee for the National Academy of Engineering’s Frontiers of Engineering Education (FOEE) symposium, Dr. Smith has helped design and implement a program for emerging engineering education leaders that broadens collaboration, facilitates learning, and promotes the dissemination of pioneering practices in engineering education. Selected participants strengthen their professional capacity for innovation at FOEE by identifying and understanding how to apply identified best practices in engineering education; developing new ideas to advance their innovations in engineering education; developing an understanding that engineering educational innovation should be guided by the evolving evidence-based body of knowledge on engineering learning; establishing long-lasting professional relationships with those attending the symposiums, and through those relationships establishing new or broadened networks with other educational innovators; and becoming agents of change to help advance the U.S. capacity for engineering education innovation.
International capacity building in engineering education and innovation

Dr. Smith has collaborated on emerging engineering education research and innovation initiatives around the world, including helping to create a doctoral program in engineering education at the Universiti Teknologi Malaysia; serving as the inaugural Engineering Education Innovation Fellow at the Hong Kong University of Science and Technology; and, with colleagues and in partnership with the *Journal of Engineering Education*, leading workshops in connection with engineering education associations in Mexico, Latin America, South Africa, India, Malaysia, Hong Kong, and Taiwan, as well as the U.S. These workshops provide a social science research foundation for disciplinary engineering faculty interested in conducting engineering education research and incorporating it into their research portfolio, using a “levels of inquiry” framework to characterize an engineering educator’s progression from a teacher who teaches as taught to one who engages in scholarship to improve performance to some who conduct funded research with graduate students. A systematic study of workshop participants indicates that they generally receive funding at a higher rate and are more successful in getting their research published in archival journals than non-participants.

Extending the engineering education research community further, Dr. Smith has collaborated on the CLEERhub (Collaboratory for Engineering Education Research) web site and offered networking sessions at the annual conferences of the American Society for Engineering Education and Frontiers in Education.

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**Key Publications**


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**Funding**

NSF Divisions of Engineering Education and Centers and of Undergraduate Education

Dr. Smith’s emphasis on rigorous research—like that supporting a paradigm shift from teacher-centric teaching to student-centric learning—underlies his work in building the engineering education research community.
Difficult concepts in science and engineering

What concepts are difficult for students to learn? How do you measure students’ conceptual understanding? Why are some concepts so difficult to learn? How do you construct learning environments that help students learn these concepts?

These questions motivate Dr. Streveler’s body of research on conceptual change and student misconceptions in engineering, which aims to bring about better learning and teaching of important STEM concepts. Partnering with faculty across the engineering disciplines, she has, in three NSF-funded projects, applied the first question (Which concepts are difficult for students to learn?) to transport and thermal science, engineering mechanics and electric circuits, and optical engineering. This work pioneered the use of Delphi studies to collect expert judgment about difficult and important concepts, thereby making a significant methodological contribution to the field.

Her creation, with Dr. Ron Miller, of the Thermal and Transport Science Concept Inventory, or TTCI (http://www.thermalinventory.com/results.html), extends the research to address the measurement of student understanding in thermal and transport science specifically. Typically multiple-choice tests designed to evaluate a student’s working knowledge of fundamental concepts in a given discipline, concept inventories provide a better understanding and assessment of student learning. Administered thus far to more than 1,000 engineering students, the TTCI—an exemplar of concept inventory development—is undergoing further development to increase its diagnostic capabilities and is serving as a test case for developing a larger research and validation methodology that will be extended to other concept inventories.

Streveler’s exploration of why certain concepts are difficult to learn, and what kinds of environments are effective in helping students learn them, bridges the gap between cognitive psychology and engineering education research. In further work, she looks at nanotechnology (e.g., microfluidics, biotechnology, genetic engineering, nanoscale machines), in which fundamental processes are characterized by small-scale dynamic systems, and extends the work of Dr. Michelene Chi and colleagues, who conclude that poor conceptual understanding results from fundamental misconceptions about how small-scale processes differ from the observable, macroscopic behavior that we experience in our everyday lives.
Dr. Streveler tests this theory by creating training protocols and materials that help students create appropriate mental models of fundamentally important dynamic processes (such as the random motion of molecules, atoms, or subatomic particles).

Future work will focus on building cross-disciplinary theories or frameworks that broadly characterize patterns in conceptual understanding. These theories will help researchers and instructors interpret and apply conceptual understanding research to the creation of effective teaching practices and assessment tools.

- **Helping engineering faculty learn to conduct engineering education research** — Starting with this essential question—*What can be done to prepare engineering education researchers to shift their focus from teaching and curriculum development to exploring fundamental questions about engineering learning?*—Dr. Streveler aims to increase engineering education research capacity that, in turn, will generate the foundational knowledge needed to fuel evidence-based curriculum reform.

She investigates and compares the epistemological, methodological, and ethical differences embedded in engineering and in engineering education and shares her findings through publications and in workshops ("What Is Rigorous Research in Engineering Education?", "How People Learn Engineering," etc.) that have reached more than 500 faculty on three continents (North America, Africa, and Asia).

Using Purdue’s nanoHUB technology, her group is also fostering a virtual worldwide community of engineering and engineering technology education researchers through CLEERhub.org. CLEERhub (Collaboratory for Engineering Education Research) is a digital habitat that functions as a knowledge base, a collaboration space, and a learning environment.

**KEY PUBLICATIONS**


Combining expertise in chemical engineering and educational theory, Dr. Phillip C. Wankat is a national leader in developing research-based methods to teach graduate students and new professors how to teach and in developing methods to improve the efficiency and effectiveness of faculty. Named a Walter L. Robb Engineering Education Senior Fellow by the National Academy of Engineering, he also received the Catalyst Award (1993) for teaching from the Chemical Manufacturers Association and both the Chester F. Carlson Award for Innovation in Engineering Education (1990) and the Lifetime Achievement in Chemical Engineering Pedagogical Scholarship Award (2004) from the American Society for Engineering Education.

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**Improving teaching** | → Dr. Wankat has had a tremendous impact in teaching engineering professors and future professors how to teach. With Dr. Frank Oreovicz, he developed “Educational Methods for Engineers” in the 1980s, a graduate course taught at Purdue and geared toward PhD candidates interested in academic careers. An NSF-funded outgrowth of that effort, their book *Teaching Engineering* (1993) marks the first comprehensive text on the subject, one that—pre-dating the emergence of the formal discipline of engineering education—borrowed from the fields of education and educational psychology for its theoretical perspective. The book opens with specific, practical teaching applications and then offers chapters on psychological types and learning, models of cognitive development, learning theories, and the evaluation of teaching. In the 1990s, *Teaching Engineering* was the second-most-cited publication in the *Journal of Engineering Education*. (It is currently available online, free, at https://engineering.purdue.edu/ChE/AboutUs/Publications/TeachingEng/index.html.)

Dr. Wankat’s second book on teaching, *The Effective, Efficient Professor* (2001), also contains research-informed material on improving one’s teaching, along with sections on time management, conducting scholarship and research, and engaging in service.

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**Trends in engineering education** | → Across a range of activities, Dr. Wankat provides a historical perspective on the field of engineering education and contributes to current analyses of the structure of research in the field. What is being published, and by whom? What becomes of the research findings?

With co-authors Drs. Jeffrey Froyd and Karl Smith, Dr. Wankat presents in the paper “Five Major Shifts in 100 Years of Engineering Education” (written for *Proceedings of the IEEE*) an examination of the factors and influences that have reshaped, or are currently reshaping, engineering education, up through the current emphasis on design, learning, and social–behavioral sciences research and the role of technology.

Concurrently with that project, Dr. Wankat has contributed assorted editorials in 2011 and 2012 on the cross-fertilization of engineering education R&D, exploring
the extent of knowledge diffusion in engineering education across the traditional engineering disciplines and finding disciplinary silos in place, within which (but, typically, not beyond which) engineering education findings have impact. Journals publishing these editorials include *Chemical Engineering Education, 45*(4), *IEEE Transactions on Education, 54*(4), *Journal of Professional Issues in Engineering Education and Practice* (in press), and *Journal of STEM Education, 12*(5&6).

As a consultant on Dr. Krishna Madhavan and colleagues’ iKNEER project (Interactive Knowledge Networks for Engineering Education Research), Dr. Wankat also contributes to our understanding of the engineering education research space in work that uses interactive knowledge networks and topic modeling techniques to identify researchers’ networks and collaborations. The goal: to provide members of the engineering education research community with tools and infrastructure that allow them to understand the structure and networks of knowledge within the community at any given time.

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*Teaching Engineering* (1993), the first comprehensive text on the subject, borrowed from the fields of education and educational psychology for its theoretical perspective.

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**Key Publications**

INSPIRE, the School of Engineering Education’s Institute for P-12 Engineering Research and Learning, is at the forefront of what it means to do, learn, and teach engineering at the earliest stages of learning through the high school years.

INSPIRE conducts basic and applied multidisciplinary research on teacher professional development, assessment, student learning, and informal learning, using its research findings to inform the design of engineering curricula, assessment instruments, teacher education, and STEM education policy within the full spectrum of P-12 (preschool through high school) engineering education.

The institute has partnerships with such nationally recognized educational programs as Engineering Projects in Community Service (EPICS), PBS TeacherLine, and the STEM Education Coalition. It hosted the inaugural P-12 Engineering and Design Education Research Summit in 2010 and launched the Journal of Pre-College Engineering Education Research (J-PEER) in 2011. INSPIRE also has offered teacher-professional-development programs for P-12 educators, impacting more than 850 teachers and 20,000 students.

**SELECTED RESEARCH PROJECTS**

- NSF DRK-12: R&D: Quality cyber-enabled engineering education professional development to support teacher change and student achievement (E2PD)
- NSF GSE/RES: Examining engineering perceptions, aspirations, and identity among P-6 girls
- NSF MSP: Using engineering design principles to affect how science and math are taught, this project reaches 200 teachers and 5,000 students across four Indiana school districts.
- NSF CAREER: A study of how engineering students approach innovation
- NSF GSE-RES: Gender research on adult-child discussion in informal engineering environments
In Purdue’s School of Engineering Education, an enthusiastic and committed community of scholars provides ongoing national leadership in building the discipline’s intellectual framework. Faculty and graduate students work collaboratively across the entire educational continuum (preschool through college, extending into the workplace) to develop a research base for guiding the preparation of tomorrow’s engineers. Living laboratories for conducting research include Purdue’s First-Year Engineering Program, Interdisciplinary/Multidisciplinary Engineering Program, Institute for P-12 Engineering Research and Learning (INSPIRE), and Engineering Projects in Community Service program (EPICS). A new program, the Strategic Knowledge Institute, is coming online as a collaboration with industry partners to explore ways to harness the expertise of practicing engineers in diverse work settings.

In the School of Engineering Education’s graduate program, each student creates a developmental portfolio that demonstrates how he or she meets 10 competencies that characterize what it means to be an engineering education professional (www.purdue.edu/ENE/Academics/Graduate/Doctorate/competencies):

- Synthesize knowledge
- Create knowledge
- Communicate knowledge
- Think critically and reflectively
- Apply engineering education principles to the solution of instructional or curricular problems
- Demonstrate engineering skills
- Engage in professional development
- Participate actively in professional community
- Explain and critique education policy
- Teach engineering

The graduate program provides a multitude of opportunities to develop these competencies that fit with your personal, professional, and academic goals and that help you develop as an educated citizen and agent of change. Your portfolio is the place to integrate what you learn in the program with the experiences, knowledge, and abilities that you bring with you into the program. In the course of achieving these competencies, you define who you are as an engineering education professional. Alumni of the graduate program have found successful careers in university and P-12 settings as well as in government and international policy, and are finding ways to connect with NGOs, international aid agencies, and professional organizations.
School of Engineering Education:
Past, Present & Future

1953 — The Department of Freshman Engineering, the first program of its kind in the country, is established to prepare entering Purdue engineering students for their discipline of choice.

1958 — The Department of Freshman Engineering creates Purdue's first honors program, for academically advanced engineering students.

1969 — The nation’s first Women in Engineering Program is founded in the Department of Freshman Engineering.

1969 — The Interdisciplinary Engineering Program is created.

1974 — The Minority Engineering Program is founded in the Department of Freshman Engineering.

1975 — The National Society of Black Engineers is founded at Purdue.

2004 — The School of Engineering Education is established, the first of its kind in the nation. The school brings together the First-Year Engineering Program (formerly the Department of Freshman Engineering), Interdisciplinary/Multidisciplinary Engineering Program, and a new graduate program in engineering education.

2006 — The first PhD is granted in the field of engineering education.

2006 — INSPIRE (Institute for P-12 Engineering Research and Learning) is founded in the School of Engineering Education.

2008 — The Ideas to Innovation Learning Laboratory opens, engaging first-year students in the engineering design process.

2009 — The Kamyar Haghighi Headship of Engineering Education is endowed.

2010 — The Dale and Suzi Gallagher Professorship in Engineering Education is endowed.

2012 — The Crowley Family Professorship in Engineering Education is endowed.

2014 — The School of Engineering Education marks its first decade.
Our Vision | A MORE INCLUSIVE, SOCIALLY CONNECTED, AND SCHOLARLY ENGINEERING EDUCATION

Our Mission | TRANSFORMING ENGINEERING EDUCATION BASED ON SCHOLARSHIP AND RESEARCH

Our Goals
EMPOWER OUR PEOPLE: Empower all members of the School each to contribute to the success of our integrated, multifaceted mission while achieving their individual professional goals.

SET THE PACE: Offer a full suite of undergraduate and graduate programs that set the global standard in engineering education grounded in and contributing to cutting-edge scholarship and research.

TACKLE THE BIG (RESEARCH) QUESTIONS: Create a world-renowned interdisciplinary research concentration at Purdue that addresses the big questions and challenges facing STEM education, with particular emphasis on engineering.

GROW THE COMMUNITY: Identify and build global partnerships and collaborations to elevate our research capabilities and those of the wider engineering education community, while simultaneously facilitating the sharing of experiences across the global community of engineering education scholars.
How do we prepare graduate students for careers in academia?

How can authentic problems be effectively used to support student learning across multiple learning objectives?

How do engineering students learn to think with models?

How does engineering thinking develop in informal learning environments?

How do we define what we mean by “engineering” influence who becomes (or doesn’t become) an engineer?