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This paper elaborates and formalizes the opening remarks made by the chair of the organizing committee at a recent workshop on innovation and entrepreneurship. Held at Harvey Mudd College in May 2011, and supported by HMC's Center for Design Education and the National Science Foundation, Mudd Design Workshop VIII provided a forum for engineers and designers—in their roles as educators, researchers, and practitioners interested in learning and in design—to identify and articulate important aspects of innovation and entrepreneurship in design and engineering education. The remarks summarized below were intended to bring to the community's attention the entrepreneurs who developed and implemented some truly innovative ideas in engineering education. Many of these ideas are now 'best practices,' yet the innovators themselves are largely unrecognized. The story of these ideas and their originators also serve to remind us, as members of engineering faculties, that all too often we are remiss in maintain our institutional memories and passing down our own history.

**Keywords:** innovation; entrepreneurship; engineering education; Harvey Mudd College



An innovation is the 'implementation of a new or significantly improved product (good or service), process, marketing method, or organizational method in business practices, workplace organization or external relations'. Acting as innovators and as the translators of new or existing technology into innovations that benefit society is the torch that engineers are expected to carry. Multiple vague and overlapping definitions of innovative behavior by engineers lead to much confusion in our society over the role that engineers play or can play in the innovation process. In this paper we explore the innovative behavior of engineers and the relationship of that innovative behavior with the creative, problem solving, design and entrepreneurial behavior of engineers. These different perspectives of defining the innovative behavior of engineers, or, as we call it, 'innovativeness' in engineers, illustrate the societal confusion over the definition of innovative behavior by engineers. The key question that we propose to answer is: 'What set of intrinsic abilities (skills, knowledge, personality traits, or attributes) when combined with domain knowledge, experience and other extrinsic factors enable and inspire engineers to create innovations that benefit society?'

**Keywords:** creativity; innovation, problem solving; engineering design education



Modeling is a core skill for engineering students and a pervasive feature of the engineering curriculum. Engineering students engage in modeling anytime they use an equation, flow chart, force diagram, or any other representation of some physical phenomena regardless of discipline. In this way modeling relates to both design process and analysis; however, students do not always recognize the full and nuanced ways that these two interact. This paper reports results from our research that is exploring the role that computational, analytical, and modeling abilities play in innovation, in the context of engineering design education. Our study reports results on faculty and students' conceptions on the role of modeling in design. Specifically, our study sheds light on the variations in how faculty and students describe how to model a design idea or solution, and the different ways each group perceives how models can be useful/helpful in the design process. Our findings indicate that students recognize the descriptive value of physical models but mention the more abstract mathematical or predictive nature of modeling less often. In addition, we found significant differences between students and faculty responses in providing mathematics or theory as an approach to modeling a design solution.

**Keywords:** modeling; conceptions; design; adaptive expertise



It is a primary goal for designers to create not just high quality designs, but new and innovative designs. The means to promote creative ideation on a consistent basis, and the conditions under which designers create new ideas are not well understood. In this paper we discuss preliminary research on reflective practices used by designers in idea generation. We present a variety of reflective practices used by design students in coming up with new insights and ideas. We offer a clarified definition of reflective practice, derived from Donald Schön's concept of reflection-in-action and prior studies of our own. Lastly, we propose and assess a framework for characterizing reflective practices.

**Keywords:** reflection; reflective practice; design; reflection-in-action; reflection-out-of-action

**Roger Burton, Lizabeth Schlemer** and **Linda Vanasupa** 275–285 Transformational Innovation: Reflections on How to Foster it in Engineering Education Systems

This paper describes the educators' disposition that we believe is required for transformational innovation. Innovating in this domain relies on interrupting existing patterns. This interruption requires the conscious recognition of patterns through an active practice of self observation. Though self observation does not necessarily need a collective process, it is served by encountering the diversity of views present in groups. Innovation in this sense consists of a fundamental identity shift in the human system and the innovators themselves. Unlike the processes of problem solving and process improvement, transformational innovation requires insight into the individual and collective attention of the designers. It also allows access to unexamined mental models and apparent cause and effect relationships. The praxis of transformational innovation within organizations looks like an active practice of reflection, experimentation and learning within the human system. We explain the theoretical perspective, suggest a protocol to begin experimenting with self observation for the purpose of pattern interruption, summarize preliminary results from a year-long process of action research involving over 25 university agents in such a change process, and comment on the limitations and risks in the protocol.

**Keywords:** innovation; disruptive innovation; transformational innovation

**Kimberly E. Bigelow** 286–292 Student Perspectives in an All-Female First-Year Engineering Innovation Course

In Fall 2008 the University of Dayton first offered their restructured first-year design course entitled Engineering Innovation. A year later an all-female section of the course was offered, in conjunction with the development of a Women in Science and Engineering Living Learning Community. Now having finished the second year of this initiative, this paper focuses on student perspectives of having been in an all-female engineering design class. Reflection papers written by the students detailed both perceived benefits and consequences of the all-female class experience. This paper examines these perceptions and discusses the implications these perceptions have for teaching traditional mixed-gendered innovation courses so that they might be more inclusive to all students.

**Keywords:** engineering design; women in engineering; first-year experience; project-based learning; living learning communities

**Kimberly Lau, Sara L. Beckman** and **Alice M. Agogino** 293–301 Diversity in Design Teams: An Investigation of Learning Styles and their Impact on Team Performance and Innovation

In this paper, we examine the role of diversity in design team performance, and discuss how diversity factors affect the dynamics and success of a design team. In particular, we focus on diversity in learning styles, as defined by Kolb's Experiential Learning Theory. We also consider other demographic factors, such as discipline and gender. We present data gathered over two semesters of a multidisciplinary, project-based graduate level design course offered at the University of California at Berkeley. The data were captured through a series of surveys administered during the semester, first to collect diversity information on learning styles and standard demographics, and then to assess team performance as students reflected on their team interactions. We examine and compare the overall learning style breakdown of students in the class, along with an analysis of the teams. The results of our analyses offer insights into how students with different learning styles appear to contribute to design team performance. We provide recommendations that will help inform design educators on how to enhance overall team performance and innovation, with an understanding of learning style differences.

**Keywords:** learning styles; design teams; team performance; Kolb's experiential learning

**Jinny Rhee, David Parent** and **Clifton Oyamot** 302–309 Influence of Personality on a Senior Project Combining Innovation and Entrepreneurship

A pilot multidisciplinary engineering senior design project incorporating innovation and entrepreneurship was undertaken at San José State University in the 2010–2011 academic year. The influence of personality domains described by the Big-Five (extraversion, agreeableness, conscientiousness, emotional stability, and openness) on individual student performance, group experience, and attitudes towards multidisciplinarity, after the conclusion of the first semester of a two semester experience, are explored in this paper.

**Keywords:** multidisciplinary capstone project; Big-Five; Five-Factor model

**Michele V. Manuel, Ann F. McKenna** and **Gregory B. Olson** 310–316 Supporting Students' Technical Innovation in Capstone Design: Insights into the Human Connection

Educating and guiding undergraduate engineering design teams that perform at a high technical level in innovative design projects can be accomplished by using a hierarchical coaching model. The coaching model discussed in this paper incorporates the use of graduate students as coaches to mentor successful design teams. This paper discusses the results of a study performed on undergraduate engineering design teams and their graduate student coaches during two consecutive years of a capstone design course. The results of this study reveal two underlying themes that can be attributed to the successful execution of this model. One theme is the development of human connections between the coach and undergraduate design team. Another theme that arose was the need for mentorship of the graduate student coach, especially on technical management skills. Both themes enable the design team and coaches to become involved in the design project for reasons beyond that of just understanding fundamental engineering concepts and solving complex problems.

**Keywords:** coaching; capstone design; teams and teamwork in design; design pedagogy; engineering design; technical management

**Elizabeth M. Gerber, Jeanne Marie Olson** and **Rebecca L. D. Komarek** 317–324 Extracurricular Design-Based Learning: Preparing Students for Careers in Innovation

Government and industry depend on educational institutions to play a pivotal role in preparing the future workforce for careers in innovation. Yet students learn how to innovate through practice, and opportunities for practice are limited in higher education. This paper addresses this challenge by presenting a new student-led approach to innovation education called Extracurricular Design-Based Learning. This model allows students to practice innovating solutions to authentic, pro-social, and local challenges in an extracurricular setting. This paper provides an overview of the model and its implementation in Design for America at Northwestern University. Findings from surveys, daily diaries, interviews, and observations suggest that students build innovation self-efficacy through successful task completion, social persuasion, and vicarious learning in communities of practice with clients, peers, industry professionals, and faculty. Further, students report achievement in learning outcomes outlined by the Accreditation Board for Engineering and Technology.

**Keywords:** innovation; self-efficacy; extracurricular; design-based learning

**Mary Kathryn Thompson** 325–338 Fostering Innovation in Cornerstone Design Courses

The boundaries between engineering design and business are becoming increasingly blurred and the need to produce innovative, entrepreneurial engineering students is growing. This work explores the meaning of innovation and how innovation is currently included in undergraduate curricula. It presents an 8 element model for encouraging innovation in cornerstone design courses based on a required cornerstone design course at the Korea Advanced Institute of Science and Technology (KAIST). The difficulty in measuring innovation in student design projects is discussed, the limitations of proxies for innovation such as patents and publications are demonstrated, and the impact of national and disciplinary culture on innovation proxies is examined. The challenges and limitations in continuing design projects after the end of the semester and for incubating technology developed during the semester at KAIST are described and a follow-up course on innovation and entrepreneurship is proposed.

**Keywords:** engineering design; first year; education; innovation; entrepreneurship



Engineering practice is multidisciplinary by nature. While some engineering projects may require discipline-specific specialists, the vast majority of engineering practice is carried out either by an engineering team of mixed disciplines, or by individual engineers who are competent across multiple fields. In both Canada and the US, engineering accreditation boards have recognized the need for students to develop at least a modest level of competency to function in multidisciplinary teams prior to graduation. Recognizing the growing need for enhanced design education and multidisciplinary competency for undergraduate students, in 2005 Queen's University introduced an elective series of courses known as the Multidisciplinary Design Stream (MDS), available to students from all engineering disciplines. The first course in the stream is offered over one term at the third year level and incorporates a broad range of lecture topics and interactive learning activities that are further reinforced with a concurrent design project in multidisciplinary teams of four students. The continuing course spans the final two terms at the fourth year level and enhances students' design, professional, and problem solving skills through their application in multidisciplinary teams on funded, industry-sponsored projects. Every team is supervised by one or more faculty members or 'engineers in residence', all of whom have significant engineering professional practice experience. The MDS has been filled to capacity since its second year of operation. Student feedback after graduation is very positive, and client response has typically been outstanding, reinforced with a very high rate of year over year client return. Student surveys and a design skills assessment provide significant evidence of increased design competency.

**Keywords:** multidisciplinary; design; engineering education; industry project; design education; professional practice; capstone; integrated learning; team design project



Design is a non-linear process that typically begins with the identification of a problem or unmet need. Once the problem is properly defined, customer needs can be determined, target specifications can be established, and potential design concepts can be generated. Needs finding is essential for established companies and start-up ventures and is an important skill for engineers to possess.

In many senior capstone design courses students choose from a list of project ideas presented to them at the beginning of the course. This provides more time to complete remaining phases of the design process, including building and testing prototypes. However, this practice bypasses the first phase of design and prevents students from gaining experience in defining problems and identifying unmet needs. Engineers working in industry will be involved in finding opportunities where technology can be used to solve problems, and will work closely with marketing, sales, and other personnel to identify new product development opportunities. They will also need to work with users of various products and technologies to identify problems and unmet needs. Students would be better prepared for careers involving new product development if, as part of their undergraduate education, they gained experience with the problem identification phase.

A new course for junior biomedical engineering students at Marquette University was developed in 2008 to expand their knowledge of and experience with the problem identification phase. The course includes several active and collaborative learning components and requires students to observe medical and surgical procedures in various clinical environments to learn how technology is used to solve medical problems. This experience develops the student's clinical literacy and their listening and ethnographic observation skills. They learn how to work with medical personnel to identify problems and unmet needs. This course allows students to experience the first phase of design and helps them develop design and entrepreneurial skills. It prepares students for careers involving the development of innovative new products for established or start-up companies.

**Keywords:** medical device design; needs finding; problem identification; new product development



Over the last decade, many courses have been created in the hopes of getting engineering students more excited about innovation and entrepreneurship. While most of these courses have aimed to teach students business acumen, we believe that, under the right circumstances, traditional engineering courses can get students excited in these topics as well. We present Mechanical Engineering 218 Smart Product Design, a graduate-level mechatronics course sequence at Stanford University, as an example of such a class. In this paper, we explore, in detail, the personal, contextual, and interpersonal factors which comprise ME218's enterprising learning ecology. We also highlight some of the immediate and longer-term outcomes of the course, including gains in students' innovation self-confidence and entrepreneurial intentions.

**Keywords:** mechatronics; learning ecology; innovation; entrepreneurship



In 1973, Horst Rittel and Melvin Webber introduced the term 'wicked problems' to describe problems characterized as volatile, uncertain, complex and ambiguous. Although that description has been around for some time, it has seen resurgence in the literature in the past few years with the increased recognition that the problems with which we grapple globally are indeed wicked. Framing of the problem is often the most difficult and important element of dealing with wicked problems, and yet much of our education system focuses on solving rather than framing problems. Recent interest in 'design thinking' focuses on problem framing, and provides a framework for teaching students the skills they need to do problem framing. This paper reports on an approach used to teaching problem framing, and in particular the skills needed to effectively engage in framing: empathy, insight recognition, thinking divergently, and learning through failure.

**Keywords:** wicked problems; problem framing; design process; storytelling; empathy, insight; divergence; iteration



In this paper we assess the appropriateness of open organizing as a model for re-designing design education. First, we review prior work on open organizing, particularly open innovation, to understand what makes these approaches novel and successful. Next, we draw on empirical findings from field studies of open source software projects that leverage open innovation principles and outline the advantages that accrue from interacting with external communities and participants, thereby increasing the authenticity of projects, and of making the design task the cornerstone of the learning activity—as opposed to structuring learning around a person. Finally, we synthesize lessons for creating open design experiences and offer suggestions that are equally applicable to in-class undergraduate design projects and to informal design projects undertaken by students.

**Keywords:** open innovation; design education; authentic learning



In this paper, we present an educational approach to facilitate Learning how to Learn, that is, to equip our students with competencies needed to become lifelong learners and succeed in the job market of the near tomorrow. Our approach is anchored in educational and instructional theory and closely tied to current professional practice. The approach is implemented in a graduate level engineering design course that is offered in a distributed collaborative distance learning setting.

**Keywords:** design education; distance learning; personalized learning; cooperative learning; competency-based learning; learning how to learn; sharing to gain, mass collaboration; crowd sourcing; globalization



The government of Singapore is launching a new university, the Singapore University of Technology and Design (SUTD), that is scheduled to take in its first freshman class in April, 2012. SUTD, in collaboration with MIT and Zhejiang University, is striving to establish a 21st century innovation paradigm that recognizes the synergy between innovation and design. Many aspects of such an exciting development are of interest to engineering educators and particularly to design educators and two are covered in this paper. One challenge addressed in this paper is the possibility for conflicting agendas between design-centric education and the goal of becoming a leading research-intensive university. An overview of research intended to address this conflict—that of the International Design Center that is jointly part of MIT and SUTD—is given. It is argued that, rather than conflicting, design-centric education and research-intensity are synergistic for a 21st century university. The second challenge discussed in some depth is the setting of 'culture' for the new institution that encourages bold attempts to improve the world through technical innovation ('innovation culture') with breadth in national cultures ('global culture') bridging from Western to Asian perspectives. Relative to the latter item, a central feature is the 'Eastern Cultural' curriculum items being developed by a second SUTD partner university—Zhejiang University (Hangzhou, China). The breadth of national cultures and a wide academic disciplinary base as part of the education process are postulated to be enablers for developing a strong 21st century innovation-leadership-culture for the modern research university.

**Keywords:** design-centric education; culture; research-intensive university; design research; design theory



Entrepreneurship is one of the contemporary expectations to engineers and their training at engineering schools. But what is entrepreneurship? We propose three different conceptualizations of entrepreneurship in engineering and design programs. They are: (1) the technology-driven promotion response centered in technological development; (2) the business selection response strategy centered in business skills (which should be additional to the technical skills); and (3) the design intervention response strategy focused on a network approach to technology, business and society. These conceptualizations are response strategies from engineering communities, professors and institutions to perceived challenges. We argue that all engineering educators deal in one way or another with the three response strategies when approaching issues of curricular design, academic reform and the international accreditation of programs. To illustrate our argument, we present the three response strategies as they are found at the Technical University of Denmark (DTU). We also discuss the different perceptions of the role of engineering knowledge they entail. One radical response is found in the case of the DTU program, Design and Innovation. This was conceived as a deliberate attempt to constitute the third response strategy as an alternative to the first, which we argue is the dominant strategy in engineering programs around the world.

**Keywords:** entrepreneurship; response strategies; engineering design; DTU's D&I program



Professionalism, which includes engineering ethics, is recognized as a valued topic in industry and education but it is difficult to teach and assess. This paper presents a web-based professional responsibility instrument and accompanying rubric, which is used to assess student understanding and skill in analyzing areas of strength and opportunity surrounding a professional responsibility issue associated with the student's design project. Students completing the assessment most frequently rated work competence as both highly important and an area of team strength while issues of sustainability were least frequently cited. The scored results of this assessment revealed that students were moderately effective at relating issues of professional responsibility to situations within their projects as well as addressing them in a responsible manner. In a post-assessment survey, students and faculty rated the assessment as somewhat accurate to mostly accurate. An inter-rater agreement study of the assessment showed that scorers were on average within one level of difference on the scoring rubric 97% of the time. Results of administering the assessment in a capstone course can be easily packaged and presented as part of a program accreditation self-study.

**Keywords:** assessment; professional responsibility



Changes in the economy and workforce needs have driven many engineering schools to consider offering entrepreneurship education to their students. Although entrepreneurship education is believed to be complementary to an engineering education, little is known about the degree to which it plays a role in contemporary students' academic programs. The purpose of this study was to explore a broad array of attitudes toward and outcomes of entrepreneurship education on engineering students in order to understand the characteristics of students participating in related courses and activities, the nature and extent of their involvement, entrepreneurship's role in their career plans, and its impact on entrepreneurial self-efficacy. Survey data were collected from 501 engineering students enrolled in senior-level capstone design courses at three institutions with established entrepreneurship programs. The study found that while two-thirds or more of engineering students intended to work for medium or large size companies after graduation, a similar number felt that entrepreneurship education could broaden their career prospects and choices. Less than one third of those surveyed felt that entrepreneurship was being addressed within their engineering programs or by engineering faculty. Students who had taken one or more entrepreneurship courses showed significantly higher levels of entrepreneurial self-efficacy on a number of measures. Students in certain engineering disciplines such as electrical and mechanical engineering were found to participate in entrepreneurship education at higher rates than others. The results of this study provide valuable baseline data that can be useful for program development and evaluation.

**Keywords:** entrepreneurship; engineering education; assessment



Engineering entrepreneurship demands a broad range of skills and knowledge, extending far beyond technical expertise in an engineering domain. Motivation and proactive behavior, professional skills (*e.g.*, communication, leadership, business), and creativity in problem solving are among the attributes linked with successful entrepreneurship. An extension of the Center for the Advancement of Engineering Education's Academic Pathways Study, this survey- and interview-based study of engineering undergraduates examines the potential of extracurricular activities to help students develop these entrepreneurial attributes.

Quantitative analyses show positive relationships between entrepreneurial attributes and involvement in engineering and non-engineering extracurricular activities. Preliminary interview analyses illustrate how these activities foster entrepreneurial attributes and contribute to students' engineering education experiences, in general.

**Keywords:** entrepreneurship; undergraduate engineering education; extracurricular activities



As an increasing number and proportion of engineers engage in endeavors that involve technical, socio-economic, and cultural complexity, there is likely an increased need for broader skill sets than those honed in typical engineering coursework. In particular, much of engineering education is focused on developing problem-solving skills in situations for which there is an accepted problem-solving paradigm. However, when novel problems arise and a prevailing paradigm ceases to work properly, these problem-solving skills are likely to be ineffective, resulting in inconclusive or flawed results. Future engineers must therefore learn to identify when the prevailing paradigm is flawed and successfully manage such situations in order to solve problems for which no readily available solution exists. To help engineering students develop such skills, educators should likely provide educational experiences that motivate students at both a cognitive and meta-cognitive level and allow students to recognize potentially flawed paradigms so they can tackle ambiguous and ill-structured problems. In many ways, the skills required for this type of problem-solving parallel the attributes of another class of professionals—entrepreneurs, as entrepreneurs routinely seek to break with accepted norms and pioneer new approaches to problems they observe in their environment. With this analogy in mind, this paper presents results from the implementation of an entrepreneurially oriented case study as a means to enhance engineering student attitudes and perspectives on problem-solving and learning.

**Keywords:** case-based reasoning; engineering education; problem-solving; ill-structured problems; engineering entrepreneurship



Many engineering departments use the capstone engineering design experience to introduce students to additional skills that will be required of them in professional practice. Two skills that can help young engineers are the ability to work in interdisciplinary teams and a good understanding of the business implications of their work. Young engineers entering an industry job are likely to be immediately placed into a division or team that is comprised of people from a wide variety of educational backgrounds, including other engineering disciplines and, depending on the industry, individuals with business, marketing, public relations, policy or science backgrounds. While students often leave their undergraduate education with a firm grasp on the fundamentals of engineering, they often have not been trained to consider the business aspects of their work. This paper describes the efforts and early outcomes at Rice University to incorporate entrepreneurship concepts into our interdisciplinary capstone design program.

**Keywords:** engineering design; interdisciplinary design; entrepreneurship; capstone design



Design Heuristics are prompts that encourage design space exploration during concept generation. Design Heuristics were developed by analyzing trends in innovative products and patterns in ideation by engineering and industrial designers of varying experience levels. In this study, 48 freshmen engineering students were given a short design task and a set of twelve Design Heuristics Cards. Each card described a heuristic, and gave two examples of its application in a product. Students were asked to create new design concepts using the heuristics. The results showed that the concepts created without Design Heuristics were less developed, and were often replications of known ideas or minor changes to existing products. However, concepts created using Design Heuristics resulted in more developed, creative designs. Students often applied the same heuristic in multiple ways, supporting our premise that the heuristics lead to exploring multiple solutions. The results also showed that some students readily applied the heuristics, while others struggled to understand how to apply them.

**Keywords:** Design Heuristics; concept generation; design pedagogy



Different approaches to design teaching in a Mechanical Engineering curriculum should coexist in order to highlight different aspects in engineering design. Two examples are given, one emphasizing product development and the other engineering analysis.

**Keywords:** engineering design; engineering analysis; entrepreneurship; product development; structural mechanics



Tomorrow's engineers must be able to work effectively in multidisciplinary teams. In response to this challenge, universities are broadening engineering design curricula. This paper describes two educational programs at the University of California, Berkeley, that engage undergraduates from multiple disciplines in design education: 1. {design.}, a student-initiated course on the basic human-centered design process and philosophy; and 2. the Human-Centered Design Course Thread, a certificate program in which students take multiple courses across departments that are thematically linked to human-centered design. We present the organization and management of these programs along with descriptive statistics on student participation. We also explore the impacts these programs have had on participating students' multidisciplinary design education, particularly: pursuing design as a career, participating in the multidisciplinary design community, and broadening perspectives of design.

**Keywords:** design; human-centered design; design education



A key role of universities is to prepare students to work in their chosen profession upon completion of their degree program. Engineering capstone design courses are often the only required courses that challenge students to draw on nearly all of the students' previous collegiate learning experiences and to synthesize and apply these to creating a new solution to an engineering problem. Aside from internship and co-op experiences, these are often the first courses that expose engineering students to some of the technical and political issues that they will often face in their professional engineering careers. Industry often looks at these design experiences in addition to work experience when evaluating new graduates. While beneficial, there remains a perceived disconnect between what academia is producing and what industry is seeking. Industry is seeking 'engineers' who are well versed in the application of science to problem solving whereas academia is producing 'engineer scientists' who are well versed in the science, but lacking in the application of knowledge gained through experience. While some context-based learning opportunities are emerging much earlier in the engineering curriculum, the needs and means to provide such experiences remain limited. This paper discusses a pilot study that was conducted during the first term of a two term capstone design class in aerospace engineering aircraft design at Virginia Tech. The study explored the educational impact of utilizing realism and simulation to introduce the aircraft design process with the aim of determining if such an approach could help remedy the academia/industry disconnect and at