Contents

Clive L. Dym Mudd Design Workshop XI
Design Education and Practice – How Process Matters

Guest Editor
Gordon G. Krauss
Department of Engineering, Harvey Mudd College, USA

This paper provides a high-level summary of the presentations and associated discourse from the Clive L. Dym Mudd Design Workshop XI: Design Education Practice: "How Process Matters," at Harvey Mudd College from May 30 to June 1 of 2019. An attempt is made to encapsulate the key ideas that emerged from both the presentations and discussions of the participating engineering design educators, practitioners and researchers.

Recent decades have seen calls for scholarship related to engineering education innovation. While some focus on how to identify "what works," critiques such as "what works won't work" raise questions about what might be valuable to disseminate with respect to educational innovation projects. In this paper, we explore this issue by asking: What perspectives are useful for bringing to the surface insights that come out of a specific case of innovating, and with these perspectives, what knowledge do we gain? The approach involved reflection conversations, an analysis of these conversations for critical moments, identifying perspectives that help to bring the critical moments into focus, and then clarifying specific insights associated with each perspective. In the results, we discuss the case in terms of practical perspectives, latent theoretical perspectives, and experiential perspectives. In particular, we name and specifically identify demanding problem definition, a discursive approach to translation, sustained coordinated action, lurking provocation, and predictable emotional labor as key insights associated with this case. We discuss how the perspectives identified may be useful for others wishing to interrogate cases of educational innovation and build scholarship in this area.

Keywords: educational innovation; capstone engineering design; interdisciplinary design; design playbook; reflection

Engineering educators face a number of instructional trade-off decisions that may be experienced as tensions in curriculum design. To navigate these tensions, we present a synthesized model based on experiential learning theory, novice-expert development, and design learning and practice. Our model highlights how different mechanisms may support students in a back-and-forth movement between learning general engineering tools and that of particular cases that utilize engineering tools. With this model, we focus our attention on students' professional and personal development towards larger system learning goals that encompass engineering formation and students' personal growth. In the context of an introductory engineering design and graphics course, we utilize this model to develop a series of reflection exercises that aim to elicit students' thinking about connections between their coursework and future careers. Two student reflections are presented to illustrate the model and its features for supporting critical reflection and meaning-making of educators' instructional practice. As engineering educators are continually challenged to navigate curriculum decision-making, this paper highlights opportunities for curriculum reframing that balances the need for students' holistic personal and professional formation.

Keywords: curriculum and instructional design; experiential learning; professional formation; scholarship of teaching and learning; student reflections

Each student in a project-based engineering design course has a unique experience. Reflection is critical because it helps ensure that students learn from these unique experiences. Two prompts aimed at encouraging reflection about engineering design are compared in this work. Thirty-five students completed both prompts at the end of an introductory engineering design course. Results show that one of the two prompts, the Design Process Knowledge (DPK) critique, focused reflections on topics related to the management of a design project: what activities to do when and for how long. This contrasts with the other prompt, called "What to Make of It" (W2MoI), which elicited meaning-making about the engineering designer themselves. Students reflected on the mindsets of effective engineering designers, their emotional experiences with engineering design, and the role of teams and social interactions in engineering design. What to Make of It also engaged students in reflecting on design activities; but, instead of focusing on the management of those activities (as with the Design Process Knowledge critique), students more commonly expressed realizations about designers themselves (mindsets, emotions, and social interactions of designers). For example, W2MoI responses such as "engineering is all about people" and "don't get attached to your ideas" are contrasts to DPK responses like "make sure to spend time engaging users" and "they should go back to brainstorming later". The most direct implication of this work is in the engineering design classroom, where these two reflective prompts can be used to guide students to make different kinds of meaning from their experiences.

Keywords: engineering design; reflection; assessment

Engineering graduates must know how to frame and solve non-routine problems. While design classes explicitly teach problem framing and solving, it is lacking throughout much of the rest of the engineering curriculum and is often relegated to capstone classes at the end of the students' educational experience. This paper explores problem framing and solving through the lens of experiential learning theory. It captures core problem framing and solving approaches from critical, design and systems thinking and concludes with a table of learning outcomes that might be drawn upon in designing an engineering curriculum that more fully develops the problem framing and solving capabilities of its students.

Keywords: problem framing and solving; design thinking; design process; engineering education; learning outcomes

Chris Browne, Lynette Johns-Boast, Kim Blackmore and **Shayne Flint** Capstone Design Projects, the Project Value Map and the Many Eyes Process: Balancing Process and Product to Deliver Measurable Value to Student and Client

This paper presents a model for coaching students through open-ended capstone design projects. The model contains two novel elements: a Project Value Map for guiding, judging and benchmarking value throughout a project; and a formative feedback process called the Many Eyes Process. The Project Value Map is a teaching tool that provides a common language for describing, discussing and comparing the value of project work across many varied projects and stakeholders; and the Many Eyes Process generates feedback from multiple perspectives to guide the team in project decision-making. The Many Eyes Process is informed by four key stakeholder perspectives: self-evaluation, a 'shadow' perspective, a teaching assistant (TA) perspective and a client perspective. The Many Eyes Process is run during three Project Audit Weeks, spaced throughout the 12-week semester. The output from the Many Eyes Process provides both quantitative and qualitative feedback to the team and its stakeholders. The combination of the Project Value Map with the Many Eyes Process helps align all stakeholder expectations over the duration of the project and provides formative feedback information to enable teams to reliably benchmark a final team grade for themselves. This suggests that an emphasis on a formal, constructive, and qualitative formative feedback processes during capstone design projects helps students deliver value in their project.
Keywords: engineering education; capstone design project; formative feedback; project value map

Monica E. Cardella, William C. Oakes, Nusaybah Abu-Mulaweh and **Andrew Pierce** Human-Centeredness in Undergraduate Engineering Students' Representations of Engineering Design

This paper explores design as a process, human-centered design, and students' design process representations. In our work, our goal is for students to learn engineering design skills and methodologies that enable them to practice design processes that are human-centered. We investigate how students conceptualize and articulate their design processes through different reflective activities where a pedagogical goal is that they also become reflective practitioners. In this paper, we describe two different approaches to design courses focused on human-centered design and a reflective activity allows us to understand (to some degree) students' design processes and the extent to which their design processes are human-centered. This study focuses on the experiences of two groups of students: (1) students who learn design by participating in community-engaged design projects and (2) students who learn design through a classroom-based project (i.e., without a community partner). We build on prior research to compare the two groups of students' understanding of human-centered design and their design processes.
Keywords: engineering design education; human-centered design; community-engaged design; service-learning design process; assessment

Carlos Cardoso, Ada Hurst and **Oscar Nespoli** Reflective Inquiry in Design Reviews: The Role of Question-Asking During Exchanges of Peer Feedback

Design reviews are common educational practice in domains engaged in project-based learning approaches. This is the 'learning space' where students meet with instructors, their peers and other stakeholders to discuss the progress of their work. A number of research studies have looked into various phenomena taking place during design reviews. In this study, we adopt an inquiry-driven framework to investigate how question-asking influences the quality of the feedback exchanged between peers working in different teams during design review meetings. Building on previous work, specifically in design research, we extend previous contributions not only on the role of questions as influencing the design thinking process, but also on their perceived value (by the respondents) and thus their general benefit for constructing valuable feedback in design reviews. We find that high performing student teams provide *more* and *better* feedback during peer-to-peer design reviews. Further, deep reasoning and generative design questions are perceived as more valuable than low-level questions.
Keywords: design reviews; feedback; question-asking; value

Rachel Dzombak,Kevin Pham and **Sara Beckman** Learning Design: Examining Programmatic Learning Outcomes and the Influence of Disciplinary Perspectives on Design Pedagogy

Design education continues to interest students across universities today. Students choose among myriad of programs that provide pathways to becoming a professional designer, but do so through varied courses of study that depend upon factors such as the school, the program's home discipline, the student population, and the intended professional design field. When creating a multidisciplinary design certificate at the University of California, Berkeley that would allow students to take design courses from multiple fields including business, engineering, humanities and environmental design, faculty from the disciplines engaged in a series of discussions about programmatic learning outcomes. As a result, a question arose about the extent to which disciplinary perspective influences design pedagogy and the resulting training provided to the student. This paper examines learning outcomes associated with design programs anchored in four disciplines and assesses similarities and differences amongst them. In doing so, it aims to uncover ways in which disciplinary focus influences programmatic goals and to identify implications of differences among them for the construction of multidisciplinary design programs.
Keywords: learning outcomes; design education; multidisciplinary design; design pedagogy

Nicholas D. Fila, Justin L. Hess and **Şenay Purzer** Instilling New Ways of Understanding the Innovation Process: Evidence-Based Heuristics from Student Innovation Experiences

In the workplace, engineers face complex technological landscapes, critical and nuanced user needs and societal problems, and intense rivalry from competitors. To address these challenges, engineering programs have increasingly emphasized knowledge, skills, and mindsets related to innovation. Yet, innovation is a complex phenomenon (spanning diverse processes and environments), which can make it challenging to provide these opportunities and frame them within appropriate learning contexts. Recently, researchers have explored course design heuristics to bring expert reasoning, creativity, and efficiency to course design tasks. This study seeks to develop course design heuristics for innovation education by building upon two previous studies. In the first study, phenomenography supported the identification of distinct and hierarchically-varied ways of experiencing innovation among engineering students. In the second study, critical incident technique and thematic analysis led to identification of experiences that supported more comprehensive ways of experiencing innovation. In the current study, we reverse engineer heuristics by investigating instructional approaches that facilitated the critical incidents and how they supported new ways of experiencing innovation. Thirty-one undergraduate engineering students from 13 different engineering majors and over 40 distinct innovative design experiences participated in this study. Through a collaborative, inductive content analysis process, we identified 55 strategies (or what we refer to as Innovation Heuristics) evident in the critical incidents (e.g., features of instruction, the learning environment). These strategies were categorized into seven themes: (1) contextualize; (2) situate; (3) guide; (4) support; (5) challenge; (6) motivate; and (7) extend. The paper describes and details each theme and the associated Innovation Heuristics that supported innovation learning, including key examples from the data and how they may be used by instructors.
Keywords: innovation, heuristics; course design heuristics; instructional strategies

Xiao Ge and **Larry Leifer** 650–663 When Tough Times Make Tough Designers: How Perplexing Experiences Shape Engineers' Knowledge and Identity

In this paper, we frame design as a learning process where discomfort abounds, and through the process, engineering designers iteratively reconstruct their knowledge and identity. Design and design thinking require very different kinds of cognition and behavior than engineering science. How engineers deal with their cognitive and epistemic biases while navigating sociotechnical complexities in design is a research topic that has been extensively investigated. Yet, much focus is on its know-how, leaving the actual experiences of knowledge development an underexplored domain. To reveal the internal experiences of designers, we conducted a longitudinal qualitative psychology study at a one-academic-year-long engineering design innovation course. Based on the empirical work, we theorize about a psychological phenomenon of designers stretching their mind in discomfort and confusion – perplexity. Each micro-activity of designers' reshaping of design knowledge and identity is conceptualized as a four-stage "Death Valley" of unlearning and reframing: schema incongruence, cognitive dissonance, pattern recognition, and schema resolution. We unfold how the emotional, cognitive and motivational components of the process are qualitatively different from other processes through which engineers fail to develop design knowledge in schema-incongruent situations. In the end, we discuss the potential value of inducing disturbances for learning, and draw implications for how to better construct engineering students' learning experiences.

Keywords: engineering education; engineering design; design innovation; design knowledge; identity work; educational psychology; cognitive growth

Marie Paretti, Daria Kotys-Schwartz, 664–674 Leveraging the Capstone Design Experience to Build Self-Directed Learning
Julie Ford, Susannah Howe and **Robin Ott**

Capstone design courses, an established component of undergraduate engineering curricula, offer students the opportunity to synthesize their prior engineering coursework and apply professional and technical skills towards projects with practical application. During this experience, capstone faculty enable mentored exploration, coaching students to navigate the design process to complete complex, open-ended projects. These projects typically require specific knowledge and skills that students need to independently identify and develop. Findings from our study of recent graduates during their first year of work suggest that this self-directed learning experienced through the capstone design process provides critical preparation for professional practice. In this paper, we examine self-directed learning in capstone and at work in detail, highlighting critical challenges in managing both knowledge and time. The findings point to important ways that capstone design educators can design projects and mentor students to help promote this critical skill.

Keywords: self-directed learning; professional preparation; capstone design; school-to-work transition; design process

Tiffany Madruga, Sitoë Thiam, Andrea 675–686 Reviewer Perspective Impact on Design Review Feedback
Vasquez, Ragini Kothari and **Gordon G. Krauss**

Classroom based design reviews teach engineering students how to generate, deliver, and receive effective feedback. Feedback is a critical part of the design process, and so, it is important to study methods to improve the quality of the feedback. This study examines the prompted perspective of student reviewers where the perspectives adopted are either positive, balanced, or critical. The impact of these perspectives on the quality of student reviewer comments in the context of an introduction to engineering design course is measured across three design reviews. Students review teams presenting their work and give them written feedback on their designed artifact, design process, and presentation. Presenting team members individually evaluate each feedback comment quality across dimensions of ease of use, professional tone, originality, and importance. This study found that: 1. Prompted perspective has a statistically significant impact on the studied quality metrics and, 2. Over the course of the class, the three different design reviews by students resulted in statistically significant changes in the quality metrics.

Keywords: engineering design review; design feedback; peer feedback; reviewer perspective

Sitoë Thiam, Tiffany Madruga, Andrea 687–701 Is it Really a Choice Between Quantity and Quality for Peer Feedback?
Vasquez, Ragini Kothari and **Gordon G. Krauss**

Generating and sharing authentic feedback is the first step to improving a design process and design artifact. Receiving the feedback meaningfully is the second step towards improvement. There are various ways feedback can be given, and designers respond differently to each. However, designers cannot respond to feedback they never receive. Design reviews are helpful because they hold a space where feedback is sought after and exchanged. However, design reviews can be challenging for novice designers to navigate. Grades, fear of reciprocation, and social entanglement amongst students can factor into a design student's ability to participate in design reviews productively. Due to these factors and others, students may not provide enough high-quality feedback to help their peers improve on their design process. In this study, the authors investigate if the quantity of feedback peers provide each other can be increased through a manipulation of the expected quantity of comments advertised to students. The authors also examine the relationship between increased quantity of feedback and the average quality of the comments across dimensions of ease of use, professional tone, originality, and importance. The findings indicate a slight decrease in comment quality at the highest expectation of feedback quantity. However, this decrease in some dimensions of quality, while statistically significant, may not be practically limiting with respect to the overall value of the feedback. Identifying the threshold of diminishing returns on quality for quantity may be useful for practitioners when establishing expectations on feedback.

Keywords: feedback; peer feedback; anonymous feedback; feedback quantity vs. quality; gender; student design

Steven Weiner, Micah Lande and 702–711 Designing (and) Making Teachers: Using Design to Investigate the Impact
Shawn S. Jordan of Maker-Based Education Training on Pre-service STEM Teachers

This qualitative study examined how a maker-based education workshop affected 20 pre-service STEM teachers' views of the lesson planning process. Design is used as both an epistemological link between making and teaching practices as well as an analytical lens through which lesson planning could be interpreted and understood. The findings of this study suggest that pre-service teachers who have been introduced to maker-based principles and practices are able to imagine a lesson planning process that is more student-centered and active than the kind which they normally utilize. While there was a contrast between the content of making-based and traditional lesson planning processes, the pre-service teachers' designs of these processes were largely the same: linear, verbal, and only occasionally reflective or iterative. These characteristics match those of novice designers.

Keywords: maker-based education; teacher training; professional development; design epistemology

Robert P. Loweth, Shanna R. Daly, 712–731 Assessing Needs in a Cross-Cultural Design Project: Student Perspectives
Jiangqiong Liu and **Kathleen H. Sienko** and Challenges

Effective identification and evaluation of stakeholder needs is an important part of cross-cultural design projects that greatly increases the likelihood of project success. Engineering students are increasingly participating in cross-cultural design projects; however, few studies have described what processes students use when identifying and evaluating needs in cross-cultural settings. This study followed an undergraduate student team as they conducted a needs assessment in a rural South American community. From this experience, participants developed conceptions of best practices for identifying their own subjectivity, soliciting many stakeholder perspectives, and engaging their partner community. However, participants also struggled to employ a variety of data collection methods strategically and analyze their data effectively. To address these challenges, engineering students require pedagogical support in specifying goals and collecting and analyzing qualitative data.

Keywords: needs assessment; cross-cultural design; design education; case study; co-curricular projects

Ade Mabogunje, Neeraj Sonalkar, Larry Leifer, Neelima Parasker and **Mark Beam**   732–748   Regenerative Learning: A Process Based Design Approach

The paper addresses the question – How do we design a process that will enable people who do not have access to design education to learn embodied knowledge at a time when there is a major shift in the dominant technology in society? In normal times, the conventional approach is to enroll in a four-year degree college or a community college, and thereafter go to work in industry. However, this conventional approach is time-consuming for the students, and impractical for companies, who, faced with the disruption of innovation often require employees with several years of experience. Thus, a gap between knowing and doing is created which does not serve well those who need to learn and earn at the same time. We therefore propose a regenerative learning paradigm for design education. We support this proposal with a case study of SnapIT, a design development firm in the software industry, and present a theory which helps us understand the regenerative learning paradigm and process.

Keywords: design education; software development; innovation; disruption; learning; regeneration

Justin C. Major, Adam R. Carberry and **Adam N. Kirn**   749–761   Revisiting a Measure of Engineering Design Self-Efficacy

An important step in the growth of engineering education as a unique field of inquiry is to understand how theoretical constructs manifest within different engineering contexts. Replication and reproducibility studies should be conducted to support and ensure results are valid and generalizable across different variations of the same context, and to support and ensure research in engineering education maintains an integral role in the development of future engineers. This study follows the previous work of Major and Kirn to replicate and re-validate Carberry and colleagues' work to create an engineering design self-efficacy instrument. Exploratory and confirmatory factor analyses of data collected from students enrolled in active learning environments reveal that students' confidence and perceived success to complete design tasks combine into a single factor. Additional work is needed to further explore this emergent inconsistency and refine the model used to assess engineering design self-efficacy.

Keywords: engineering design; self-efficacy; study replication and reproducibility

Vivek Rao, George Moore, Osita Anders Udekwu and **Björn Hartmann**   762–772   Tracing Stories across the Design Process: A Study of Engineering Students' Engagement with Storytelling in an Undergraduate Human-Centered Design Course

Stories help design teams develop shared understanding and vocabulary throughout the process of developing solutions and prototypes. While stories are widely acknowledged to be essential to the design process, their use by novice designers in university settings remains relatively unstudied. In this work, we examine the story practices of undergraduate engineering students enrolled in a one-semester human-centered design project-based course. We develop a coding framework grounded in narrative theory to quantitatively describe the presence of story and its constituent elements in student work. We also integrate three simple interventions in the course to facilitate students' use of stories. After examining assignments ($n = 162$) spanning six iterations of the human-centered design process, we find that students show marked increases in their use of stories in the context of their prototypes. We also find limited improvement, or in many cases, a decline, in students' use of stories in the observational and frameworks stages of the process. These findings suggest a relationship between design project iteration and novice designers' use of story, building on previous research relating professional designers' differing use of story across design phase. This work invites several opportunities for design educators to incorporate facilitation of storytelling practices into their design courses.

Keywords: storytelling; design education; human-centered design; design process

Giovanna Scalone, Cynthia J. Atman, Kenya Mejia, Hannah Twigg-Smith, Kathryn Shroyer and **Aaron Joya**   773–795   Dealing with Ambiguity: Leveraging Different Types of Expertise to Guide Design Questioning

Questioning is important for understanding the fundamental design process. Design itself can be viewed as a question driven process. When we consider question-asking behavior as a means to manage convergent and divergent modes of thinking by decreasing or increasing ambiguity, expert designers draw either from domain knowledge and/or their situational transactions. In engineering education, it is important for engineering students to acquire an epistemological inquiry process as well as learn how to operate in the concept domain. In order to develop an understanding of question-asking behavior in design and of how we can include both divergent and convergent thinking in design, we wanted to explore how design experts use their expertise to solve a complex problem through questioning. To do this, we took an inductive approach and examined the question-asking behavior of 6 expert designers during a 3-hour verbal protocol analysis where they were asked to design a playground. Three were domain experts (playground designers) and three were non-domain experts (engineering designers). Through our work, we learned that all the design experts in our sample ask questions and that their questions occur throughout their design process. Questions that decrease ambiguity were prevalent for all participants in our sample, particularly in the beginning phases of their design process. In instances where the design experts increased ambiguity through questioning, the questions were distributed among the questions that decrease ambiguity. The questions posed by the engineering design experts were predominantly based on technical aspects whereas the playground design experts posed questions related to community aspects in order to understand the social and physical situation. From our work, we conclude that the range of variability in the kinds of questions posed depends on the kind of constraint the design experts choose to focus on, their experience and the kinds of knowledge used. In this study, the questions posed helped the design experts understand and push problem boundaries as they engage in both convergent and divergent design behaviors. This has implications for teaching question-asking techniques to help students with their design process and outcomes.

Keywords: questioning; domain expertise; design processes; convergent and divergent thinking; design cognition

Sheri D. Sheppard, Tua Björklund, Helen L. Chen, Shannon K. Gilmartin, Sara Atwood, Eric Reynolds Brubaker, KJ Chew, Philipp Christov, Catie Cuan, Patrick Danner, Barbara Karanian, Abisola Coretta Kusimo, Leif Luehmann, Vikas Maturi, Chieloka Mbaezue, Fabian Schäfer, Christian Schnell, George Toye and **Marsie Trego**   796–813   Connecting People and Ideas: Making Sense of a Research Lab through Creating a Shared Frame

This paper looks at the culture of an academic research lab. Our aim is to internally reflect on how the connections between ideas and individuals can be noticed and labeled in order to create a shared cultural frame. We use a case-study approach with a sensemaking lens using the Markus-Conner Culture Cycle as an underlying model. Following a sensemaking process, a series of individual and small team reflection exercises served as our data source. Graphical and narrative exercises illustrated several of the connections within the Culture Cycle. Analysis of these exercises made visible the individual interests and values in research, articulated a shared institutional mission with parallel individual narratives, and connected key ideas that the lab brings together as a shared frame for a lab research agenda with collective elaboration. While the particulars of this case study are specific to Stanford University's Designing Education Lab, we invite and challenge any academic lab to increase the transparency of their culture and leverage the interconnections among individuals, interactions, institutions, and ideas in order to inform and educate future researchers and expand knowledge.

Keywords: culture; reflection; organizational values; mission; inclusion; bias

Leadership is a significant teamwork process in industry and student engineering design teams. Capstone design and additional student design team experiences provide students with the opportunity to develop team skills in addition to applying other engineering skills acquired during their undergraduate education. They also offer an opportunity to provide training and education to students on leadership skills. Six faculty members were interviewed in this study to determine faculty perceptions of the emergence and distribution of leadership in student teams. These interviews were conducted within the context of a research campaign including case and protocol studies designed to understand engineering leadership in these novice design teams. The interviews were analyzed using elaborative and inferred coding and additional analysis techniques. The results informed the development of case and protocol study objectives and approaches and provide an increased understanding of leadership within these teams from the faculty perspective.

Keywords: engineering leadership; collaborative design; concurrent design; Capstone design; design research

Knowledge about design processes is fundamental to engineering education. Nevertheless, this is a broad topic that, by definition, touches on all aspects of design practice. This paper presents a novel curriculum for design education that is shaped around the design process and specific activities within the design process. The three themes explored in this paper are: 1. The importance of the design process in defining the program; 2. The relationship between the design process and the program structure and program learning outcomes (PLOs); and 3. The students' understanding of the design process as a consequence of participating in the program. Section 1 presents background material on the importance of design process knowledge in engineering education and provides a brief overview of models of the design process. Section 2 presents the design of the Bachelor of Engineering program in Industrial Design at Xi'an Jiaotong-Liverpool University: the role of design within the university, the distinctives of the program, and the definition of program learning outcomes. Section 3 presents the design and results of a student survey to evaluate the students' awareness and confidence in design process knowledge. Section 4 provides conclusions and suggestions for future work.

Keywords: design process; design thinking; BEng industrial design