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Mudd Design Workshop IX
Design Thinking in Design Education
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through the lens of the Dreyfus and Dreyfus model of skill acquisition. We demonstrate how this theory of skill acquisition explains specific results found in the literature and the challenge of developing design ethnography as a skill. We also discuss the pedagogical implications of this model of design ethnography learning and consider Kolb's theory of learning as it applies to the development of students as design ethnographers.

Keywords: design ethnography; design expertise; design education

Design Thinking has been used in educational courses in high-income countries to address challenges in lower-income, resource-constrained environments. Most of these courses present the need of low-income communities as the context in which students learn and practice their Design Thinking. The interaction with lower-income communities is limited to need finding and product testing. There is a dearth of Design Thinking courses situated wholly in resource-constrained environments and consequently a gap in our understanding of how a Design Thinking curriculum might work in a resource-constrained environment. In this paper, we describe the development of a Design Thinking curriculum for venture creation in Nigeria and India using Schön's framework of reflective design practice. The paper presents eight principles that were used to frame a Design Thinking curriculum and outlines the key insights learned from the process of designing and implementing seven prototypes of a Design Thinking curriculum.

Keywords: design thinking; curriculum development; venture creation; reflective practice; resource-constrained environment

Conceptual design has been modeled as a loop cycling from design entities that stimulate cognitive processes that produce design operations that in turn generate design entities, continuing iteratively. In order to deepen our understanding of this iterative process and therefore enhance design training, the cognitive processes of design iteration can be further broken down in terms of a spectrum of thinking informed by dual-process theory and Cognitive Continuum Theory. This spectrum ranges from purely intuitive to purely analytical processes and encompasses a number of modes of thinking in between. Built on this framework, we discuss results from mapping cognitive processes from the design realm onto this continuum and observe that some iterative loops stay in the analytical mode, some in the intuitive mode, while others quickly oscillate back and forth. A relationship between the character of ideas generated and cognitive mode is explored, as mapped by linkography, a visual representation of the connections between design entities in a task. Potentially, ideas that are generated during analytical loops are more derivative while ideas generated during intuitive loops or intuitive-analytical oscillations are more unique. To conclude, implications for design education based on this analysis are proposed.

Keywords: dual-process theory; design cognition; iteration; intuitive thinking; conceptual design

''Development engineering'' is a new interdisciplinary field that we define as creating solutions that improve human development at scale in low-resource settings. We posit that design thinking is the core of development engineering, but needs to be augmented for development applications to emphasize: (1) Incorporating development goals, constraints and opportunities; (2) Scaling for impact; and (3) Integration of novel sensors, experiments, and large datasets (e.g., from the Internet, satellites, and mobile phones). We used this framing of development engineering as the basis for a newly formed Ph.D. minor at UC Berkeley. This paper describes the foundational course in the program, elective courses and the theory and practice seminar. We provide lessons from our formative evaluation along with recommendations for improvement.

Keywords: design for development; development engineering; design thinking; design education

Does the use of a matrix tool in a design selection task help novice designers select the objectively best design even when they have seen a fixating design and are working under time pressure? The use of matrix tools in a design selection process can improve the selection decision, help identify shortcomings in the concepts, and indicate potential concept combinations. A quantified score for each concept can be calculated using a selection matrix assuming that the customer weights accurately reflect the importance of each function and the performance of each function is accurately measured. In these circumstances, a selection matrix is able to address and eliminate issues of bias in concept selection. Yet, the application of such tools may only be accomplished in introductory design courses in a superficial manner and may be less effective in practice than they could be. Limited time to apply the matrix tool and exposure to a fixating design example are two factors theorized to reduce the likelihood of using a selection matrix and to completing it properly. This study evaluated the ability of novice designers to overcome bias in a design selection process through the use of a selection matrix when time pressure was present vs. absent and when a fixating design was present vs. absent.

Keywords: matrix tools; fixation; selection bias; time pressure; design

Education in America can benefit from innovation. Inventive thinking from a diverse array of people and experiences can help redefine and reinvent this important public mission. Hackathons are collaborative, short sprints that offer such collaboration opportunities. While usually coding marathons, hackathon-type events like the Education DesignShop have been developed to address broad, systemic issues, tools, and processes from design thinking. Two research questions are explored: *How do non-designers transform into design thinkers?* and *How do educational projects address systemic changes?* The Education DesignShop introduced new ways to collaborate and form sustainable solutions. Eight key structural components are identified around just-in-time modules teaching design thinking in an educational context. Projects from the Education DesignShop show a larger number of designerly attributes and are farther along Anderson's Continuum of Systemic Change. Policy implications suggest ways to support further propagation of design thinking to address problems around education.

Keywords: design thinking; hackathons; design thinking learning; systems thinking; policy

TheDesignExchange is a site dedicated to the support and development of the design thinking community. Its mission is to provide an online space for design thinking practitioners to share, discuss, and explore design thinking, allowing both novices and practitioners to expand and hone their expertise. Though there are many introductory experiences and courses available in design thinking, it is often difficult to find resources and support for advancing to the next stage of professional development, an aspect of which is being able to intelligently choose among the myriad methods available, rather than relying on the subset of methods learned in school. *TheDesignExchange* aims to fill that void by organizing the available design thinking methods, developing a community of design educators and practitioners to evaluate those methods, and helping educate the next generation of design

innovators. This paper focuses on insights gained from two practitioner workshops associated with ideation and prototyping methods and describes the results of pilot testing with product design students in an upper division multidisciplinary course at UC Berkeley.

Keywords: design thinking, design methods, ideation, prototyping

Shawn Jordan and **Micah Lande** 1438–1444 Additive Innovation in Design Thinking and Making

A Maker is a modern-day tinkerer and hands-on builder of DIY artifacts. Makers create their inventions wholly out of their imaginations, with the support of a rich collaborative online and in-person community. This paper describes the results from a qualitative study of adult Makers and their characteristics of collaboration in the Maker community. Results indicate that Makers exhibit a mindset of Additive Innovation. This describes the open community of sharing and learning that is the Maker community. Connections between engineering and Making are also discussed.

Keywords: making; maker community; design thinking; innovation; design process

Gordon G. Krauss and **Lawrence Neeley** 1445–1457 Peer Review Feedback in an Introductory Design Course: Increasing Student Comments and Questions through the use of Written Feedback

Feedback plays an important role in the design process. In formal design review situations, presenters receive and respond to questions from reviewers. The authors hypothesize that structural and social barriers may complicate and degrade the feedback process. In this paper, the authors examine the peer feedback process for the culminating presentations of a preliminary conceptual design project in an introduction to design, manufacturing, and management course, E4, at Harvey Mudd College. Student design teams present their design process and the resulting design artifact to their class section. The other students in the section provide feedback to the team. Teams presented their design reviews as either live presentations or via video and were reviewed by teams through either live oral questions and answers or in written comments using a handwritten or online form. The specificity and motivation from the instructors for feedback also varied by section. The video section responded to evaluator comments in class and was able to receive clarification about the comments. The authors of this study are able to note the differences in quantity of feedback, the type of feedback, and the response to the feedback by the design teams. The study suggests that (1) students in this course may not be open with their feedback during oral question and answer periods, (2) that simple tools such as written feedback will gather more information than question and answer periods and (3) that class time may be used to discuss feedback rather than for presentations effectively to provide better feedback and interaction.

Keywords: peer review; feedback; written feedback; oral feedback; student comments

Adam R. Carberry, Samantha R. Brunhaver, Kristine R. Csavina and **Ann F. McKenna** 1458–1471 Comparison of Written versus Verbal Peer Feedback for Design Projects

Engineering design project courses offer an opportunity for students to develop their communication skills. Developing such skills through written documents and verbal conversation are important to ensure students possess the professional skills required of practicing engineers. The following paper includes two complementary studies that utilize peer feedback comparing: (1) written versus verbal feedback and (2) second-year students to seniors. Study I investigates the impact of multiple means of expression and action in two concurrent sections of a second-year project course. Study II compares students in the second-year project course that used verbal feedback with students in a senior capstone course that used the same verbal feedback approach. Our findings suggest that providing students with the option of giving verbal peer feedback encourages them to provide a higher percentage of critiques with elaboration versus surface critiques without elaboration. We also observed senior students to have further developed the skill of providing constructive criticism, as opposed to just criticism, both on technical and professional content.

Keywords: peer feedback; design; communication

Ken Yasuhara, Ryan C. Campbell and **Cynthia J. Atman** 1472–1480 Where Do Engineering Students Learn to Consider Design Problem Context?

More than ever, today's engineers need to be equipped to understand the complex contexts in which they do their design work. Studies suggest, however, that undergraduate engineering programs are not sufficiently preparing students with this contextual competence. To contribute to the growing body of work investigating where and how engineering students develop contextual competence, we interviewed civil/environmental engineering undergraduates about the kinds of experiences and background they find helpful for developing specific aspects of contextual competence. They cited a wide range of helpful sources, including engineering and non-engineering courses and co-curricular activities, as well as personal experiences, family influences, and current or historical events.

Keywords: design learning; context; transfer; qualitative research; civil engineering

Monica E. Cardella, Heidi A. Diefes-Dux and **Farshid Marbouti** 1481–1491 Written Feedback on Design: A Comparison of Students and Educators

Design students improve their understanding of design, their design skills, and their design project work through experience and through feedback. Feedback might come from other students (i.e. peer reviews), educators, end users, and other stakeholders. In this paper, we focus on two of these groups: other students and educators. We investigate the differences between the types of feedback that educators provide compared to the types of feedback that students provide in peer reviews. To accomplish this, we asked 19 educators and 120 first-year engineering students to independently provide feedback on the same sample student work. Our findings suggest that there are both quantitative and qualitative differences between educators' and students' feedback; compared to the students, educators provided a greater number of comments, provided longer comments, and exhibited different patterns in terms of the Focus and Substance of the feedback. In addition to our findings, we discuss our approach for helping educators and students develop their ability to give productive feedback.

Keywords: design education; first-year engineering; feedback

Golnaz Arastoopour, David Williamson Shaffer, Zachari Swiecki, A. R. Ruis and **Naomi C. Chesler** 1492–1501 Teaching and Assessing Engineering Design Thinking with Virtual Internships and Epistemic Network Analysis

An engineering workforce of sufficient size and quality is essential for addressing significant global challenges such as climate change, world hunger, and energy demand. Future generations of engineers will need to identify challenging issues and design innovative solutions. To prepare young people to solve big and increasingly global problems, researchers and educators need to understand how we can best educate young people to use engineering design thinking. In this paper, we explore virtual internships, online simulations of 21st-century engineering design practice, as one method for teaching engineering design thinking. To assess the engineering design thinking, we use epistemic network analysis (ENA), a tool for measuring complex thinking as it develops over time based on discourse analysis. The combination of virtual internships and ENA provides opportunities for students to engage in authentic engineering design, potentially receive concurrent feedback on their engineering design thinking, and develop the identity, values, and ways of thinking of professional engineers.

Keywords: design thinking; engineering design; assessment; online learning; learning sciences; virtual internship

Jenn Stroud Rossmann 1502–1507 Engineering Design as a Liberal Art: A First-Semester Introduction to Design Thinking

First-year students are introduced to engineering design as a socio-technical mode of engagement. The new course in Design Thinking, taught within the structure of a required (for engineers) "Introduction to Engineering" framework, develops a socio-technical understanding of engineering and design. This perspective follows from innovations in engineering pedagogy. The course establishes engineering design as a component of the liberal arts in two ways: first, sharing creative, innovative, and cultural elements with other liberal arts disciplines; and, second, being a mode of inquiry and building understanding of the world. Like other Introductions to Engineering, this course provides a cornerstone design experience, and involves first year students in an engineering design environment that emphasizes collaboration, communication, and interdisciplinarity. More uniquely, this Introduction to Engineering module introduces design as a method not simply of problem solving, but of problem defining by applying design thinking, through the development of empathy with all stakeholders and interrogation of their (geographical, social, cultural, environmental, etc.) context. Following this introduction, students—no matter what major they pursue—may integrate design thinking into the array of perspectives and methods that comprise a liberal education. The development, implementation, assessment, refinement & evolution of this approach to this introduction to design thinking at Lafayette College are described. Although this work has been performed in the context of a liberal arts college, both methods and results suggest opportunities for educators at larger schools and traditional engineering institutions to structure an introduction to engineering design with a core of socio-technical concepts.

Keywords: cornerstone; design thinking; liberal art; socio-technical; liberal education; first year students

Matthew T. Siniawski, Sandra G. Luca, Jose A. Saez and **Jeremy S. Pal** 1508–1513 Design Thinking and Service-Learning for First-Year Engineering Students

Developing empathy and understanding the unique needs of stakeholders are highly important skills that engineering students should learn. Since such skills are closely tied to the success of service-learning engineering projects, teaching design thinking to students seems to be a natural fit. As such, a simple design thinking process was recently incorporated into service-learning first-year introductory engineering courses at a liberal arts private undergraduate institution. Using a mixed methods approach, this paper examines the impacts of design thinking on first-year engineering students and investigates students' confidence in technical and professional engineering design thinking skills and if students perceive that design thinking enhances their learning of engineering and design. Our findings indicate that students who participate in a service-learning, design thinking course felt more confident with technical engineering skills and felt they learned more about the iterative nature of the design process and prototype testing. This is especially true for women, who show the highest gains in self-reported confidence with constructing design prototypes.

Keywords: design thinking; service-learning; first-year engineering students; confidence; women

Borjana Mikic and **Alan Rudnitsky** 1514–1521 An Emergent Approach to Design Thinking and Collaborative Team Composition in an Introduction to Engineering Course

Traditional approaches to design thinking in introductory engineering courses often prescribe the challenge problem, target users, and/or composition of the student design team itself. Inspired by the more fluid conceptualization of collaborative teamwork found in the OpenIDEO platform, as well as the emphasis on emergent teams and problems whose members take collective cognitive responsibility for idea improvement that is the hallmark of Knowledge Building pedagogy, we asked, how might we re-imagine the introduction to engineering experience to emphasize more emergent and collective problem definition, team composition, and individual and collective agency? The aim of this paper will be to share the process and results of this re-design in its first iteration, and place it within the context of the learning sciences.

Keywords: design thinking; knowledge building

Borjana Mikic, Susannah Howe, Fraser Stables, James Middlebrook, Angie Hauser, Chris Aiken, Reid Bertone Johnson and **Eitan Mendelowitz** 1522–1529 Design Thinking and the Liberal Arts: a Cross-Campus Initiative at Smith College

The national conversation regarding the future of liberal arts education often fixates on a false dichotomy between the humanities and STEM fields; thus, the time seems right to reimagine a framework in which the humanities, social sciences and STEM fields work in synergy to not only prepare students for creative engagement with the complex and challenging problems facing our world, but also for the active creation of the new realities that they have imagined as possible. In this paper, we describe the origins and progress to date of a pilot cross-campus initiative in Design Thinking and the Liberal Arts at Smith College, an all women's residential liberal arts college in Northampton, MA. In addition, we share insights from our experiences to assist those at other institutions who might be interested in engaging in similar kinds of endeavors.

Keywords: design thinking; liberal arts; multidisciplinary; institutional change

Ville Taajamaa, Mona Eskandari, Antti Airola, Tapio Pahikkala and **Tapio Salakoski** 1530–1539 O-CDIO: Emphasizing Design Thinking in CDIO Engineering Cycle

This study has two main objectives. Firstly to present a work-in-progress engineering education model O-CDIO and secondly to report the research results from recent pilot courses that have preceded the creation of the model. Research is based on and carried out as part of an extensive engineering education reform in a Nordic (Northern Europe) multidisciplinary science university (UNI), which started in 2011. The O-CDIO engineering education framework combines human-centered Design Thinking methods with Systems Thinking in a natural sciences context throughout the engineering education degree structure. The main goal of the framework is to educate engineering students to become problem definers in addition to problem solvers. O-CDIO builds on the CDIO structure adding emphasis to the first phases of the engineering cycle. O-CDIO framework has human-centered Design Thinking methods embedded in the engineering education structure throughout the curriculum, from day one to graduation. The second objective of this paper and the main research question is does adding Human-Centered Design Experiences affects the Learning of Transferable Working Life Skills? This is also one of the fundamental questions behind the O-CDIO model. Data for this study is firstly from pilot courses that were introduced to 229 students at different stages of their studies from fall semester 2012 to summer 2014, and secondly from 31 faculty members from the time line of January 2012 to June 2015. Both qualitative and quantitative analysis methods were used. Our results show that in the piloted courses tolerance towards ambiguity, engagement towards teaching methods and course structure are increased, and enhanced. Also, understanding towards Design Thinking practices, Problem Based Learning methods, understanding the role of teamwork and communication, even excelling and appreciating learning through teamwork are increased and enhanced. Further research for the O-CDIO framework will focus in the implementation requirements of the framework as well as more detailed description of the courses, their intended learning outcomes, and teaching methods.

Keywords: engineering education; design thinking; O-CDIO framework; human-centered design approaches

Design thinking has seen rapid growth since mid-2000s far beyond the engineering and arts disciplines traditionally concerned with design. In universities, it is increasingly being used to create programs where graduates from multiple disciplines can learn to develop a design orientation to problem solving. This rising popularity of design thinking as a generalist training methodology positioned alongside the MBA program while helpful, obscures the central role it plays in the engineering disciplines. In this paper, we argue for design thinking to be recognized as a foundational science for engineering alongside Physics, Chemistry and Biology.

Keywords: design thinking measurement; design teams; product based learning; technology innovation; innovation eco-systems; economic growth