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Cultivating Design Thinking in Students Through Material Inquiry

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Design thinking is a way of understanding and engaging with the world that has received much attention in academic and business circles in recent years. This article examines a hands-on learning model as a vehicle for developing design thinking capacity in students. An overview of design thinking grounds the discussion of the material-based specialized studio course, Felt Construction. The pedagogical context as well as the components and organization of the course are considered through case studies. The effectiveness of course design is analyzed, and the relevance to other disciplines is addressed, with the intention of providing some flexible strategies that may be used in course design where cultivating design thinking is an objective.

Design thinking may be defined as a process and a frame of mind put into action to effect positive change in the world. This strategy is touted in popular and scholarly literature as a paradigm for generating innovative ideas. Design thinking may be developed in students through a learning model that combines hands-on exploration with opportunities to apply and test the knowledge gained for the purpose of preparing today's aspiring professionals to become contributing citizens and effective shapers of the future. This approach raises several questions, including: What is the value of knowledge gained through hands-on experimentation with a raw material and how does it translate to better student outcomes in design projects? This question is explored through the examination of a design-related media course called Felt Construction, a course grounded in design thinking, studio culture, and the design process. This course was revised over five years based on observation and student feedback for the purpose of generating the most effective dialogue between student discovery, creative problem solving and the implementation of student ideas.

Design Thinking: Past and Present

The term *design thinking* has roots in various disciplines and is frequently, although not exclusively, associated with engineering, architecture and related design disciplines in early literature focused on design thinking. Donald Schön's *The Reflective Practitioner* (1983), Bryan Lawson's *How Designers Think* (1990), and Peter Rowe's *Design Thinking* (1987) are three foundational texts addressing the idea of design thinking with respect to these professions. Schön (1983) used the term *reflection-in-action*, whereas Lawson (1990) and Rowe used (1987) the term design thinking; in both cases they refered to a way of seeing and understanding the world while working to bring about desired change. Each of the authors set out to analyze the process of design and identify characteristics of design thinkers. Commonalities in the analyses of the design process include the concept of *framing*, the strategy of approaching new situations by relating them to a repertoire of past experience, the need for iteration and the importance of both divergent and convergent thinking processes (Lawson, 1990; Rowe, 1987; Schön, 1983). In other words, a designer demonstrates the capacity for recognizing opportunities for improving a situation in which the problem to be solved has not been explicitly defined. In defining the problem, the designer frames it. While approaching each new situation with attention to the specifics that make it unique, he/she is able to draw on similarities with previous experiences to help define a strategy of inquiry and intervention (Schön, 1983). Divergent thinking is associated with imagination and intuition and is said to open up the problem space, whereas convergent thinking is associated with logical and rational thought and is said to narrow in on possible solutions (Schön, 1983). Framing and evolving problems in parallel with solutions entails revisiting and revising ideas through iteration (Dorst, 2011; Goldschmidt & Rodgers, 2013; Steen, 2013). These views align closely with the philosophy expressed by Dewey (1938) where he placed value on students learning from firsthand experiences and relating their prior experiences to new information. Rather than learning from books, Dewey (1938) asserted that students learn more effectively from their environment: "What [the student] has learned in the way of knowledge and skill in one situation becomes an instrument of understanding and dealing effectively with the situations which follow" (Dewey, 1938, p. 42). The focus of Dewey (1938), Rowe (1987), and Schön (1983) on thinking, doing, and reflecting emerged out of the tension between theory and practice that has long existed, and continues to be an issue of contention, in academic professional programs. The separation of thinking from making has been attributed to the advent of industrial production (Cross, 2011). Advocates of design thinking in general education (Cross, 1982) and in higher education (Goldschmidt & Rodgers 2013; Razzouk & Shute, 2012; Rowe, 1987) have asserted the need for developing thinking as a skill in all students.

Design thinking, design process, and the value of making things by hand have gained much popular interest in recent years. The renewed interest in making is due in part to the DIY. (do-it-yourself) movement and the Maker Faire phenomenon, which offer enthusiasts of many stripes the opportunity to exercise their creative capacities. Companies like IDEO and Luma Institute have advocated and marketed design thinking as a strategy for identifying opportunities to improve the human experience. *Human-centered design* and *user-centered design* are related concepts that have traditionally been associated with industrial or product design, but are more and more being used outside of those disciplinary boundaries. These current trends highlight two of the underlying tenets of design; design implies a degree of social responsibility and the practice of design offers the possibility of seeing one's ideas materialized in the world in a concrete way. Brown and Wyatt (2010) discussed design thinking as seen and practiced by IDEO. The author identified three overlapping spaces of the process, which are undertaken in a non-linear sequence and several times throughout the design process: inspiration, ideation, and implementation (Brown & Wyatt, 2010). Although the terminology applied to these spaces varies within current teaching-related literature, the characterization of the design process as non-linear and consisting of spaces rather than steps is a recurring theme. Many authors have agreed that in an effective design process, the sequence and frequency with which the steps are undertaken will vary according to the specifics of the situation (Brown &Wyatt, 2010; Hatcheul & Weil, 2009; Lawson, 1990; Owen, 2007; Razzouk & Shute, 2012; Schön, 1983; Seitamaa-Hakkarainen & Hakkarainen, 2001; Stempfle & Badke-Schaub, 2002). Dorst (2011) characterized the design thinking process in terms of abductive reasoning where the "how" and the "what" are unknown, but the value, or the desired goal, is known. The ambiguity and uncertainty associated with design problems has given rise to the terms *ill-structured* and *ill defined*, which have commonly been used to differentiate design problems from more explicitly defined problems (Cassim, 2013; Goldschmidt & Rodgers, 2013; Reboy, 1989). Owen (2007) asserted that knowledge is generated and accumulated through action. He added that knowledge is used to produce works, which are in turn evaluated to build knowledge.

Design Thinking in the Classroom

A review of literature addressing the implementation of design thinking pedagogy reveals several consistent themes. Arguments for the intrinsic educational value of designerly ways of knowing include assertions that design activity (a) develops students' abilities to solve real-world, ill-defined problems; (b) provides opportunities for the development of concrete/iconic modes of cognition; and (c) develops nonverbal thought and communication (Cross, 1982) through various methods of making, including sketching and modeling, or prototyping (Dörner, 1999). Reboy (1989) stated that instructional design can better prepare students for problems in adulthood if projects and other more closely mock real-world situations. The persistent dominance of scientific and analytical thinking in education and the need for balancing these with other modes of cognitive activity are cited as both obstacles to, and rationales in favor of, incorporating elements of design thinking into instructional design (Cassim, 2013; Cross, 1982).

Another recurring theme in the literature is the value of hands-on learning. Dowling (2012) traced the lineage of kinesthetic creation in pedagogical design from the Renaissance to the present day. Pestalozzi's espousal of active, hands-on, and self-directed learning in the 18th century, Froebel's hands-on exercises or "gifts," Piaget's constructivism, and Kolb's experiential learning and constructionism constitute a long history of support for kinesthetic learning in pedagogical design. Dowling (2012) followed this theoretical grounding with an example of a full-scale design and building project embedded in a design technology course. In the two-part assignment, students prepare a schematic design for a space between two existing interior volumes. Quarter-scale models, 3-D drawings, hand sketches, and written research are among the tools used to investigate and develop a solution. In the second phase, teams select and modify one student's design, which is subsequently reviewed, revised and built full-scale. Dowling (2012) used this project to illustrate that tactile learning invites experimentation and exploration. She posited that kinesthetic strategies offer significant potential to a wide range of curricula, citing the benefits to students in the form of increased sensory awareness, immediate and deeper learning, and an increased sense of authorship (Dowling, 2012).

Some articles present case studies where students were observed designing and attempt to draw conclusions about design activities and the relevance of design thinking in education from these individual case studies (e.g., Lim, Lim-Ratnam, & Atencio, 2013; Seitamaa-Hakkarainen & Hakkarainen, 2001; Stempfle & Badke-Schaub, 2002). Many courses studied in the literature are interdisciplinary, situated within the traditional design disciplines or within engineering. Stempfle and Badke-Schaub (2002) analyzed the processes of mechanical engineering students designing a mechanical concept for a planetarium. Bower (2011) used an online computer programming course as an example for changing pedagogical design to better engage learners in design thinking. Donar (2011) surveyed five different design thinking courses in across various disciplines to compare course structure. What emerged from the review is the variety of ways design thinking is interpreted and applied. Authentic assessment, thinking through making, group feedback, and self-reflection play significant roles in many of the teaching-related articles consulted.

Hands-On Design in Context

In examining the impact of a hands-on design approach on students' design thinking, a design course (Felt Construction) is explored. First, however, the larger context within which the course exists is examined. This three credit professional elective is offered within the context of a school of architecture and design whose founders were students of the Bauhaus faculty. The Bauhaus School is widely recognized for its interdisciplinary, hands-on approach to design, and for its revolutionary stance on the partnership of craft and industrial production, when mass production was largely seen as a threat to craft and craft production (Simon, 2012). Here, as in a majority of design programs in North American universities today, the design studio is considered the core of design education (Simon, 2012).

First year students are enrolled in a general design studio course with their colleagues from other design majors. This interdisciplinary approach to the design studio is based on the model of the Vorkurs (introductory course) taught at the Bauhaus (Simon, 2012), and it underscores the philosophy that all design disciplines share a common language of design elements and principles. With this common foundation, students move into their respective disciplinary programs in the second year. The Foundation Design Lab is described in the course catalog as "an immersive, interactive learning environment focused on inquiry, experimentation, discovery, and synthesis." The emphasis on these modes of learning remains a hallmark of the studio throughout the undergraduate curriculum.

This general Foundation Design Lab course has much in common with the specialized studio-based, material-focused course (Felt Construction) under examination—critiques, exercises, projects, and prompts. *Critiques* are formal or informal discussions about student work that is displayed as a visual presentation or a physical model. The "desk crit" began as an over-the-desk, one-on-one give-and-take between student and instructor in architecture programs in North America, reflecting Dewey's ideas of the teacher as an active partner in the learning process (Anthony, 2012). The definition of critique has expanded from there to include dialogue in groups. Generally, both students and the instructor participate in the discussion, with the objective of revealing strengths and weaknesses in the work for the purpose of advancing the work. This format meets the criteria for authentic assessment as defined by Wiggins (1990) and Keyser and Howell (2008). In Felt Construction, students are given shorter-term exercises, and longer-term projects, the products of which are often critiqued and improved upon through iteration. Often the exercise or project is initiated through a prompt provided by the instructor. Another term commonly used is *brief* (Cassim, 2013; Goldschmidt & Rodgers, 2013; Hatchuel & Weil, 2009; Razzouk & Shute, 2012). The term *prompt* is meant to convey the open-ended nature of the exercise or project; rather than being asked to design a specific product, the prompt may define the desired characteristics or effects of a design, and will leave it up to the student to decide how best to achieve that outcome. From these few examples, one can begin to deduce that self-direction, reflection, and the capacity to communicate ideas are traits that are cultivated and esteemed in design students.

Within the context of a studio-based curriculum where interdisciplinary collaboration is valued and recognized as a necessary reality of today's work environment, a course known as Felt Construction is offered. The Felt Construction course is open to all design majors and all year levels. As a material-based elective, this course serves as a forum for students from the various disciplines to work together and to abandon preconceived notions of discipline-specific roles through the focus on the material. Because so few students are familiar with felt, the playing field is leveled and every student enters as a novice.

Why Felt?

Felt is an ancient, elegantly simple, and versatile material that has enjoyed a popularity explosion across the design fields in recent decades. From furniture and accessories to fashion and interiors, felt is sought after because of its tactile appeal and sustainability. A non-woven material made from wool, it is a fabric, yet it can be manufactured in densities reminiscent of plywood or other sheet materials used in construction today. While felt has enjoyed a renaissance among the design professions, there is still much untapped potential in the material.

Felt has been used for decades in industrial applications where it is valued for its durability, wicking, insulating, and liquid- and sound-absorbing properties, to name a few. In the United States, the Society of Automotive Engineers has rated felts according to density and other properties, ranking their suitability for specific uses and creating a system of standards that insures a reliable, narrowly defined profile (Dent, 2009).

Felt Construction: Pedagogy and Course Structure

This course has three over-arching goals: (a) building a new awareness about felt, (b) gaining an appreciation of felt's potential, and (c) creating a more effective dialogue between students' ideas and the physical felt-based artifacts they make. Knowledge of materials and an effective negotiation between ideas about form and the realities of constructing that form are powerful tools in the pursuit of excellence in design and lead to increased student agency. Indeed, the course is constructed around the value of primary experiences with physical materials for students who are learning to design the constructed environment. In *The Craftsman*, Richard Sennett (2008) wrote about the hand as a thinking tool and evoked the workshop and the laboratory as arenas of heuristic learning. He argued that iterative and hands-on practice of any vocation or craft is a singular learning experience and is a potential source of deep satisfaction for the individual engaged in such work (Sennett, 2008). Felt Construction is designed to provide a learning environment that links the head, the hand, and the material (i.e., felt) in an effective dialogue. As Sennett (2008) wrote, "Every good craftsman conducts a dialogue between concrete practices and thinking; this dialogue evolves into sustaining habits, and these habits establish a rhythm between problem solving and problem finding" (p. 9); that is, thinking through making is an important tool for cultivating habits in students that make them more effective learners, with the ultimate goal being that they not only find the best solutions to problems but that they ask better questions of themselves and their environment. This echoes Schön's (1983) discussion of problem-solving versus problem-setting. According to Schön (1983), the act of framing a situation, or defining the problem to be solved, is essential to design thinking. By doing this, designers open up new avenues of exploration through which to generate solutions. Also implicit in Sennett's (2008) formulation is the idea of tacit knowledge, wherein practice transforms the novice into an expert, and the technique becomes unconscious, leaving the goal or desired outcome as the sole focus.

The course itself consists of five elements: (a) course introduction, (b) precedent research, (c) hands-on technical workshops, (d) exhibit challenge, and (e) independent student project. Because of the interactive, intensive hands-on nature of the course, class size is limited to 14 students. This also ensures that the equipment and facilities will not be overwhelmed and that each student can receive one-on-one assistance with technical aspects of the course.

Built into the course are several ways of conveying new information to students. On the first day of class, students are provided with as complete a picture of the course-based learning experience as possible: syllabus, schedule, types of assignments, expected time commitment, grading, expenses for materials, and other logistics. Physical samples accompany a narrated PowerPoint presentation consisting of words and images. Bower (2011) cited studies in multimedia learning to support the idea that content presented in visual and auditory mode can lead to more effective learning. Students are asked to work in a variety of media throughout the semester. The mix of media and formats accommodates diverse learning approaches, providing more avenues for accessing and processing information. The class is launched with the assignment of precedent research and an overview of upcoming technical workshops. The importance of student engagement and initiative to the success of the course is emphasized. The prompt for the exhibit project is generally distributed during the second or third week.

Because the majority of students are in their junior or senior years, they come with a developed sense of their design process and a familiarity with studio practices that they bring to the course as a way of confronting an unfamiliar material. Over the years, the course has evolved to balance shorter-term exercises with longer-term projects, individual work with group activities, and technical challenges with opportunities to integrate conceptual direction and new skills. Each year, close attention is paid to the level of student engagement at each stage of the process, and student input is solicited at key points. Using two different iterations of Felt Construction, the evolution of the course model over time and the relevance to instruction in any field in which students will have a role in determining the physical manifestation of an idea will be illustrated.

Case Study: Big Felt

In the semester immediately following the set up of a new Felt Lab that supports the fabrication of large-scale pieces of handmade felt, course design was focused to take advantage of the new space and equipment through the theme *Big Felt*. The curator of a gallery space on campus was approached with a proposal for a collaborative felt exhibit that acts as a full-scale, site-specific installation. The description below frames the exhibit for viewers:

> *BIG FELT: Collaging Interiors* is an assemblage of highly tactile, interactive, site-specific spatial constructs designed and fabricated by students in the Felt Construction course. The work seeks to explore the limits of felt as a building material while considering how felt might mediate the relationship between the built environment and the human occupant. Students have created works tailored to the gallery space responding to the

temporary nature of the setting and questioning the traditional protocol for interacting with art in a gallery. The installations vary from humorous to provocative and invite participants to think about the role of felt in shaping space.

The cohort included architecture, interior design and industrial design majors or minors. Students were asked to choose from a list of suggested topics for both the precedent research and the student-led workshop assignments. Because of the ambitious scope of the exhibit, independent student projects were not included in the course this semester. Students were given the prompts for precedent research and student-led workshops in the first week, and the exhibit prompt was distributed in the third week.

The deliverable for the precedent research is a maximum 10-minute PowerPoint presentation, which the student presents to the class. The presentations efficiently build a student's background knowledge of the material properties, historical background and contemporary applications of felt by pooling the research efforts of the group. This involves students in co-creating knowledge and building their learning environment, aligning with a model of learner-centered pedagogy where the teacher acts as a facilitator (Dowling, 2012; Scheer, Noweski, & Meinel, 2012).

In week three of the semester, students were given a written prompt, which included the description of the exhibit above as well as language evoking different types of temporary interiors. Because the prompt outlines abstract concepts rather than providing more concrete parameters for the project, this can be considered an ill-structured problem. Students are therefore obligated to add their own parameters—an act of framing— to allow them to proceed. They were asked to brainstorm and bring in sketches for critique. As ideas were proposed and discussed in an informal group setting, three imperatives were emphasized by the instructor: (a) the interactive nature of the exhibit, (b) the cohesiveness of the exhibit as an interior environment, and (c) the focus on felt as a spatial medium. In response, students put forward ideas for the organization and character of the whole space as well as for their individual contributions.

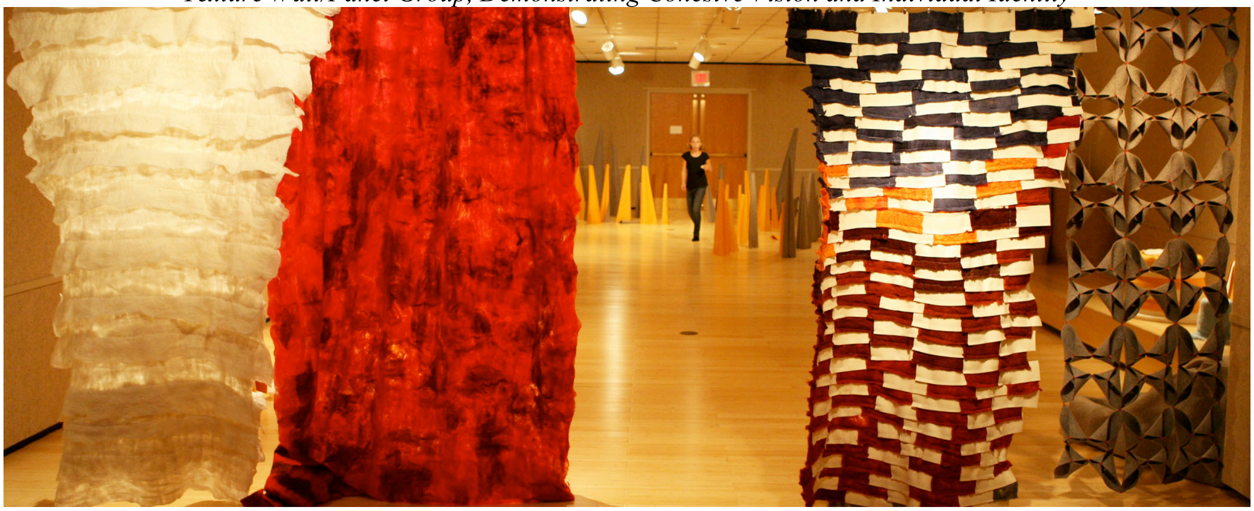
Students were also asked to select from a list of technical workshops (or suggest alternates) and run the workshop (individually or as a team) with guidance from the instructor. Examples of typical workshops are fabric manipulation (shaping industrial felt by sewing) and hand felting (making felt from raw fleece or prepared wool). Some students wanted to wait until the class had agreed upon a design direction for the exhibit before choosing a workshop. As they saw it, the workshops should be in service of the final product. As it happened, workshops that were conducted early, such as the structure/enclosure and texture workshops (both themes suggested by students rather than selected from the list) were generative, and this led to students forming teams around like interests. In a few cases, these workshop teams translated directly into exhibit teams. These subgroups provided a narrowed focus and feedback for each student's contribution to the exhibit. Once these teams emerged, small group critiques were alternated with large group critiques, to ensure that there would be a cohesive collective vision for the show as well as smaller areas or groups of objects with distinct themes. Two such groups yielded particularly strong work. In the case of the Texture Wall/Panel group, individuals designed and fabricated their own pieces, but they collectively agreed upon the way the whole group would be displayed. The Fiber Forest group took a different approach; together they designed a modular component, a felt cone whose structure was provided by a specific type of seam, and each student participated in the fabrication and deployment of the scaled multiples of the module.

The Exhibit: The Dynamic Curtain

The display organized by the Texture Panel group served to illustrate the collectively negotiated parameters and the individual expressions created within that framework. Together, the students chose to create a "gateway" to the show, hanging panels at varying heights and depths across the width of the gallery space, suggesting a thickened but porous wall on the one hand and an assembly of individual pieces with distinct identities on the other (see Figure 1). In the case of the leftmost panel, the student's design was directly related in form and technique to her own research and to the work of a designer that was introduced by the instructor. The student began with intentions to highlight the softness and translucent quality possible in handmade felt while creating a plane that branched out into a three-dimensional surface, capturing space within it. The final construction of the piece involved negotiation between technique and concept to reach the result that best embodied these intentions. The final panel, back-lit and overlapping with its red neighbor, displays the modulation in thickness of the handmade felt created by the layering of felt strips that had been hand-stitched together. Also highlighted are the variation of thickness and surface texture within each handmade strip.

The next piece is the most ambitious piece in terms of scale. Titled "Dancing on Red," the panel measured 7 ft x 10 ft and was composed of wool that was batch dyed several different shades of red and layered in a randomized pattern to create gradation. This piece pushed the limits of thinness, revealing the webbing of wool fibers. This was the only panel of the four that met

Figure 1
Texture Wall/Panel Group, Demonstrating Cohesive Vision and Individual Identity



the floor and piled in a manner reminiscent of Robert Morris' pieces, a subject of the students' precedent research.

Across the opening, "Tile Expectations 1" combined dyed handmade felt and undyed industrial felt, which were connected using techniques that are a cross between the overlapping of siding and seaming techniques used in sewing of upholstery and quilts.

"Shadow Pockets" is the final piece to the extreme right. The form of the triangular scoop-shaped unit emerged first in this student's design process and drove the composition of the whole. The units of the screen created and captured light and shadow in a visually compelling manner. The proportion of positive to negative space in this panel created a direct visual connection between the spaces on either side, while partially framing and filtering that view. The ensemble of the four panels demonstrated the use of felt as a spatial divider, a screen, and a filter with the flexibility of the curtain.

The Exhibit: Mobile Cones

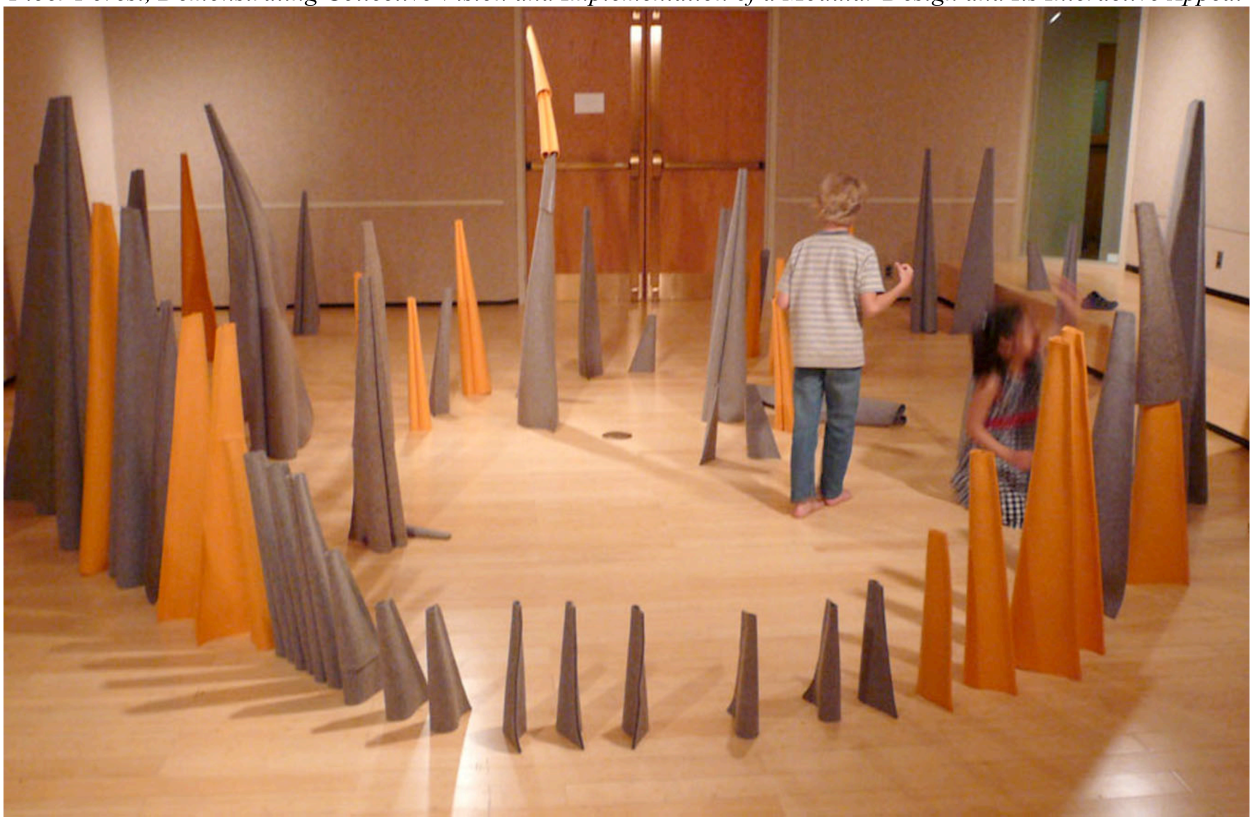
In the Mobile Cone group, all aspects of the design fabrication process were collaborative, resulting in an entirely unified exhibit display. The three students interested in developing modular components made of industrial felt worked on developing a seamed, tapered cone that would stand independent of external structure and could be assembled in large numbers to shape an environment (see Figure 2). The final design purposefully approached the slenderness ratio that would cause the pieces to tumble over. "Fiber Forest" had undeniable appeal for adults as well as children, but visitors under age 12 were the most uninhibited in their engagement with the moveable felt elements. Several visitor-constructed variations were recorded throughout the one-week duration of the exhibit, each revealing some new characteristic of the cones as space-making components.

Reflecting on Big Felt

This iteration of Felt Construction was evaluated through dialogue with students and colleagues after installation by watching gallery visitors interact with the pieces and through instructor reflection. User interactions with the environments created gave the students an opportunity to experience user feedback. The quality of the finished work served as evidence that over-arching pedagogical goals were being met, but room for improvement was also identified. The first two Texture Wall/Panel exhibit pieces clearly demonstrated the value of the precedent research, hand felting and wool dyeing workshops. Knowledge construction through hands-on workshops and exposure to the work of other designers provided the necessary impetus, technical skill, and inspiration to envision and successfully implement a design that met the criteria of the prompt. The challenges in this iteration of Felt Construction arose in the sequencing of exercises, workshops, and projects; the balance of group to individual work; and the degree of self-directed versus more structured learning that took place. In an informal feedback session at the end of the semester, one student suggested that the workshops, and the hand-felting workshop in particular which played a key role in her exhibit project, be held earlier in the semester. This input and other feedback, combined with my own reflection on the process, led me to make some

Figure 2

Fiber Forest, Demonstrating Collective Vision and Implementation of a Modular Design and Its Interactive Appeal



structural changes in the next iteration of the course. Bower (2011) emphasized the need for students to understand lower-order processes before design can be effectively learned, and Reboy (1989) cautioned that rudimentary instruction of skills should take place before requiring a student to apply those skills under more challenging circumstances.

Case Study: Felt Frontiers

In this iteration, a significant change was made to the workshop sequence and content delivery. Whereas the sequence and content of these workshops had previously been dependent on student initiative, in Felt Frontiers, workshops were organized and led by the instructor, and they focused on the introduction of specific techniques and skills, each one explored in the manner of a contemporary felt designer. These technical, hands-on workshops were conducted at the beginning of the semester, and they were paired with an assignment to allow students to immediately put their newly acquired skills into practice. Each student was asked to (1) make a physical sample using the techniques introduced in the workshop and (2) document their making process through images and text in a PDF. This series of steps built analysis and self-reflection into each workshop, as well as an opportunity to apply the newly-acquired skills within a limited scope, calling on the student's ability to synthesize his or her learning. This proved to be a more efficient strategy for accelerating the students' learning. Seitamaa-Hakkarainen and Hakkarainen (2001) compared the design process of novice weavers to expert weavers and found that the major difference in their approaches was that the novices focused on the visual composition of the textile while the experts moved back and forth between construction of the design and the formal composition, developing the two in tandem. As the technical workshops were structured to include both precedent examples and hands-on, heuristic tasks, students were able to build a larger repertoire of previous experience to draw from as they confronted the exhibit project.

The Exhibit: Modular Felt Panels

The exhibit for Felt Frontiers was held in a display space in the architecture building. Students were given a written prompt and a drawing of an oak frame to be fabricated. Each student was asked to design and fabricate four 2 ft x 2 ft modular panels exploring how felt might be used to sculpt surfaces and how the panels might be used to shape an interior. The drawing specified the construction of the frame to be incorporated into the design, including dimensions and the options for attachment to the wall, floor or ceiling. As in the case of Big Felt, some parameters of the project were defined for the students, but the openness of the exercise required students to further frame the problem in order to act. The choice of scale and parameters for this project were a counterpoint to the ambitious scale and freedom of Big Felt. The Modular Felt Panel project prescribed the size and number of artifacts that students were asked to make. While the groups brought cohesion to the Big Felt exhibit, they also delayed action and decision-making. In order to build the cohesion into the Modular Felt Panel project, the size and approximate purpose of the module were dictated. In contrast to the highly choreographed and pre-designed layout of the Big Felt exhibit, the layout of the Modular Felt Panel exhibit developed organically on the day of installation. The instructor had mapped out zones for attachment of the modular felt panels, but not individual pieces. Students arrived at the appointed time with their completed panels, and a negotiation began to determine the best groupings of pieces and the most impactful way to present the panels as a surface. After an open debate among the students, a unifying grid was agreed upon, with different spacing to separate compatible subgroups or to identify the work of one individual. Ultimately, the system had enough flexibility built into it to accommodate student preferences regarding the proximity and context of the pieces without diminishing the overall desired effect of a larger felt surface.

The direct translation from the workshop samples to the panel exhibit design was very clear in this iteration of the course. Students used techniques they learned and enjoyed or found intriguing, applying those to the larger-scale project. One student made four different panels, each building on a different technique learned in the workshops (see Figure 3). This student's work effectively demonstrates a mastery of techniques and the synthesis of numerous variables to achieve a conceptual goal.

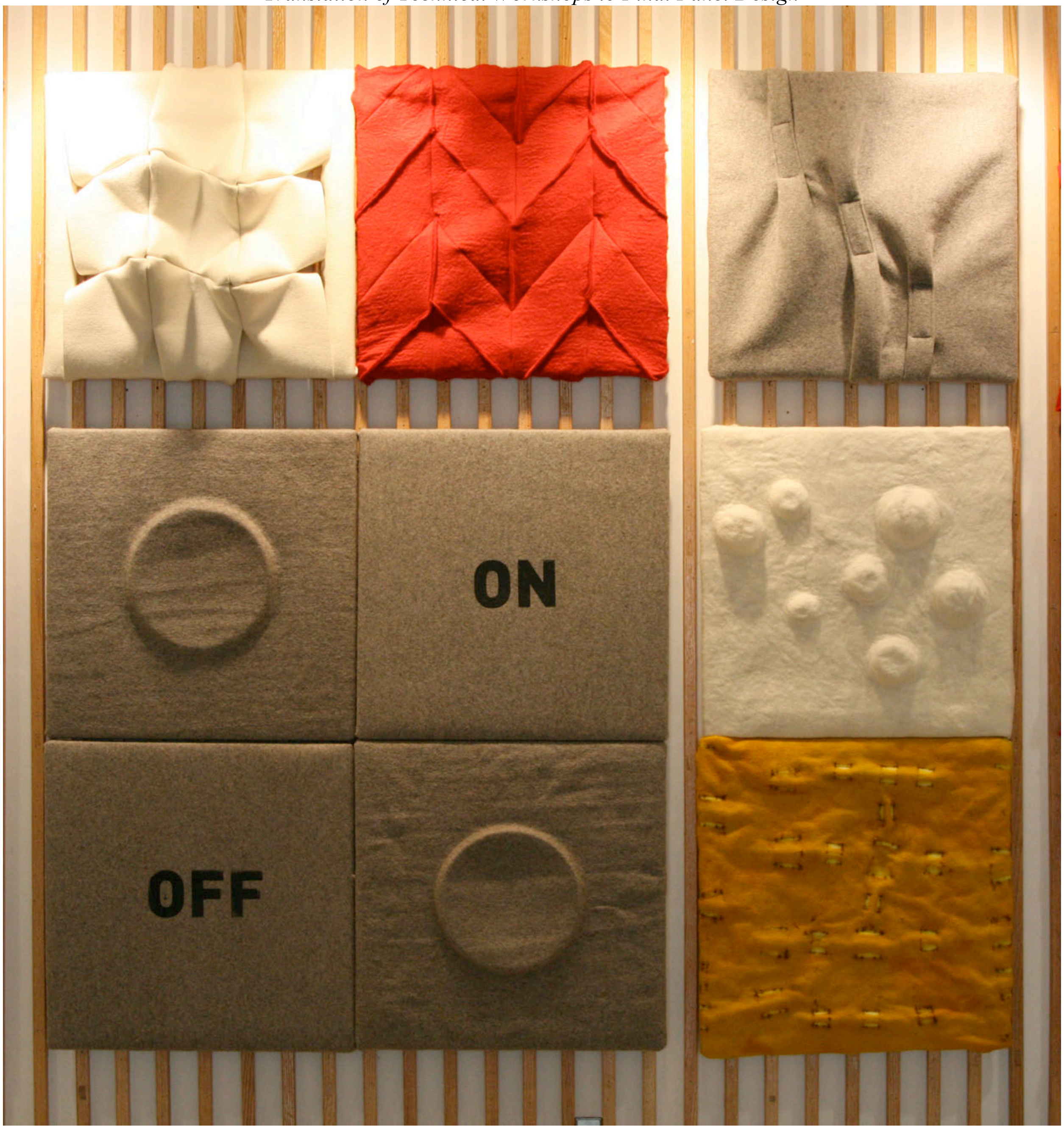
Summary Reflection and Future Directions

Reflecting on the two case studies was useful in identifying the most effective instructional methods for supporting student discovery given the course structure and content. The case studies suggest that the learning of new technical skills is more effective when separated from the application of those skills in a larger ill-structured project. This observation is supported by the literature, as mentioned earlier (Bower, 2011; Reboy, 1989). The quality of the outcomes for the workshop PDFs and samples in the second course iteration provide a compelling argument for the advantages of building reflection into this course at more frequent intervals. Because much of the information and many of the experiences are new, asking students to reflect and make sense of their experience appears to support productive knowledge building. While group collaboration imparted unity to the designs in Big Felt, students seem to be more comfortable with the indeterminacy of the project when the relationship of group work to individual work is more explicitly defined. This suggests that close attention must be paid to the balance of ill-structured and well-structured tasks included in lesson plans in order to enable student learning.

To reiterate, the five-part structure of the course scaffolds a series of design-thinking activities (e.g., reflection, prototyping, sketching) and learner-centered interactions (e.g., critiques, peer feedback, collaborative decision-making). Each element fosters design thinking and contributes to the effectiveness of the hands-on learning model in enabling students to develop new knowledge and to practice design thinking. The first course element, the course introduction, allows the instructor to model design behavior by providing students with a broad overview (i.e., systems or holistic thinking) through a multi-modal presentation. The workshops have been refined to include an assignment asking students to record their process and present it in words and photographs organized in a PDF file. This builds both reflection-in-action and reflection after-the-fact into the workshop activity. The physical sample created allows students to practice non-verbal modes of cognition, or thinking through making, also cited in the literature as important processes in design thinking (e.g., Cross, 1982; Dörner, 1999).

The reshaping of the Felt Construction course each semester is another example of the process of design thinking or reflection-in-action. Assignments have been refined and changes have been made to the course structure that provide opportunities for students to (a) use previous knowledge to connect to new information, (b) reflect on the value of new knowledge, and (c) bring new competencies to bear in a process that involves framing of a problem and negotiating between ideas and constructing form. The following question continues to guide instructional design: What is the ideal balance between theory and practice, or between freedom and structure, given the unique opportunity that presents itself each semester? Based on instructor observations, reflections and student feedback, goals for future iterations of the course include incorporating opportunities for students to benefit from user feedback and developing assessment tools that help instructor and student alike gauge the effective learning of design thinking traits.

Figure 3
Translation of Technical Workshops to Final Panel Design



Note. Upper left panel and panels in right hand column are the work of one student, demonstrating the application of techniques learned in the fabric manipulation, 3D forming, and felt dyeing workshops.

A Design Thinking Learning Model

There is a growing popularity of design thinking in fields as diverse as IT, business, education and medicine (Dorst, 2011), and design is practiced in a widening domain (Cassim, 2013). While there appears to be general consensus on the value of design thinking as a 21st century skill (Scheer et al., 2012), a review of the literature also suggests the need for more research that can provide practical guidelines to higher education instructors across disciplines for the effective incorporation of design thinking into course design (Reboy, 1989; Scheer et al., 2012).

Teal (2010) and Reboy (1989) highlighted patterns in Western education that prove to be obstacles to design thinking as a way of knowing. Teal (2010) pointed out the difficulty for students who have been educated in a system founded in the scientific method and representational thinking in adopting a non-linear model of learning. Reboy (1989) asserted that problems presented in programs for training critical thinking tend to be well structured, in contrast with everyday problems that tend to be ill-structured. Another important consideration in the successful support of design activities is the need to encourage experimentation and acknowledge failure as an important heuristic learning tool.

In this article, a studio-based, hands-on, material-focused learning model has been examined through case studies and in the context of recent scholarship on the topics of design thinking, design process, and studio culture. The core principles upon which this model is based are hands-on learning and thinking through making. It has been demonstrated how the five elements of the course structure set the stage for activities that have been identified in the literature as critical parts of the design process: reflection, sketching, and modeling as non-verbal modes of cognition and iteration. The activities that support idea development throughout the course are critiques, peer feedback, and collaborative decision-making. While the five elements of the course structure have helped establish a pattern of making, reflection, peer feedback, and the application of newly acquired skills to ill-structured problems in the Felt Construction course, the author is suggesting that instructors adapt the model to the content and unique circumstances of his/her course. In other words, it is proposed that the model will be most effective when applied with a design thinking mindset. The instructor can evaluate the elements of the course, the pedagogical goals they serve, and the behaviors or experiences they foster to better align his/her course objectives with the appropriate instructional devices. As stated in Dowling's (2012) review of experiential learning, it is important for course design to accommodate unexpected situations that arise, including the needs of students and instructor improvisations. This proposal challenges educators to engage in design thinking alongside their students, acting as an active partner in student learning, in the tradition of Dewey (1938). In this spirit, a learning environment can be created that will cultivate design thinking in students across disciplines and curricula.

Conclusion: From Felt Construction to Mind Construction

As Peter Rowe asserted, "design is a way of thinking about and knowing the world" (p. 245), and it is this type of knowing and mental agility that will prepare future professionals to confront and even help determine the shape of the future. Design thinking and the design process are intrinsically flexible and adaptable, drawing on and developing a student's capacity to frame opportunities for change and to bring form to ideas for the purpose of improving the human condition. Design problems require subjective interpretation (Lawson, 1990) and an ability to cope with uncertainty (Cross, 2011). Practicing design thinking develops in students the ability to navigate undefined territory and to act on their environments to bring about change. Higher order thinking skills such as design thinking enable students to analyze, synthesize and innovate, and thus to deal with real-world problems (Razzouk & Shute, 2012). Providing students in higher education with opportunities to develop these traits and capacities can empower them to engage in today's complex, global society and determine its form in the future.

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