International Journal of Engineering Education Vol. 38, No. 2, pp. 512–524, 2022
Printed in Great Britain
0949-149X/91 $3.00+0.00

Creating Space for Empathy: Perspectives on Challenges of Teaching Design Thinking to Future Engineers*

DIANA BAIRAKTAROVA
Engineering Education, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA. E-mail: dibairak@vt.edu

DONALD PLUMLEE
College of Engineering, Boise State University, Boise, ID 83725, USA. E-mail: dplumlee@boisestate.edu

Design thinking has generated widespread momentum today in several areas where new ideas transform our everyday lives. Engineering design schools have created and sustained a new discipline that uses the designer's sensitivity and design methods to create customer value, experience, and market opportunity. Guided by current best practices in design education we created a design thinking course and offered students content adapted from the most well-established design programs. This paper presents instructional and administrative perspectives, challenges faced, and lessons learned on adaptive design and implementation of the design thinking course within a resource-constrained environment in a small engineering program.

Keywords: design thinking; design education; empathy; engineering

1. Introduction

Inspired by current trends in design thinking philosophy and the call for creative thinking as a necessary quality for engineering students, we offered and taught an empathic design course at a Southwestern University in the United States. The course was open to graduate and undergraduate engineering students. In this paper, we describe our experiences and lessons learned from teaching and administrating the course. The course structure was adapted from most established design programs to a resource-constrained environment. Throughout the course, students explored the topics of design thinking-innovation, creativity, prototyping, empathic, and verification design. The focus of the course was learning and experiencing design as a space rather than a step-by-step process with a toy prototype as a final project. Our aim was twofold. First, we wanted to provide targeted scaffolding and support for engineering students to develop the receptivity, knowledge, and skills to enable a systemic change in the engineering learning community. Second, the course was intended to enable the learning community members to meet the innovation challenges and develop competencies for engineering practices. This paper describes the design of the course followed by an instructor's and administrator's perspectives on the course's implementation. The purpose for this descriptive case study is to provide an effective starting point for developing a structure and implementing a new course based on design thinking methodology within a resource-constrained learning environment and to offer the engineering education community a practical contribution to the sphere of teaching engineering product design.

2. Literature Review

To situate this work in the literature, we first illustrate the need for a more holistic approach to engineering education and review the premise of design thinking to meet this need. Then, we discuss other efforts implementing design thinking into courses at aspirational peer institutions.

2.1 Future Changes in Engineering Education

The fast pace of change in engineering has generated a stronger focus on broader learning objectives in engineering education. The "grand challenges of the 21st Century" have fueled demands from government agencies, industry, academic institutions and accreditation bodies, for engineering graduates to demonstrate both technical and social skills [1]. The National Academy of Engineering (NAE) presented characteristics for 21st century engineering graduates in its "Engineer of 2020" report, including strong analytical skills, creativity, communication, leadership, professionalism, and resilience [2]. Moreover, the Accreditation Board for Engineering and Technology (ABET) requires that engineering graduates achieve a number of learning outcomes including those that address social dimensions of engineering. A few of the recently updated ABET outcomes with explicit social dimensions include specific Student Learning Outcomes: (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare,

* Accepted 12 November 2021.

as well as global, cultural, social, environmental, and economic factors, (3) an ability to communicate effectively with a range of audiences, (4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts and (5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives [3]. Developing learning outcomes that can effectively address these broader social dimensions of engineering practice can be difficult to incorporate into courses [4]. This is particularly relevant for resource constrained institutions that have limited instructional capacity. However, implementation of the practice of design thinking could help address these expected outcomes as research suggests [5].

2.2 Definition of Design Thinking and Basis for Definition

Design thinking is a human-centered design approach that helps designers explore and generate new ideas to solve complex problems, with empathy for the user of a design as the priority in the process and iteration of steps as a key feature [6–9]. Tim Brown defines design thinking as "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity" [10]. Brown then adopts a perspective on business and marketing, which perhaps was influenced by the venue of his piece in Harper Business [11]. The expanded scope suggests that design thinking is not a method restricted to engineering and architecture but is one that can be used in various contexts where solving problems or meeting needs is a point of concern.

Among all the definitions in the literature, the human-centered formulation of design thinking aligns most closely with the Stanford d.school and IDEO's conceptualization of the approach [10, 12]. The Stanford d.school communicates design thinking as a five-phase process: *empathy*, *define*, *ideate*, *prototype*, *test* [13]. The first phase, *empathy*, involves getting to know the user and seeking to understand their needs. The *define* phase focuses on taking the lessons learned from the *empathy* phase and identifying a specific challenge that needs to be addressed. In the *ideate* phase, the designer or design team comes up with possible alternative solution ideas. The *prototype* phase involves coming up with a physical form to present the potential solution in a more concrete manner. In the *test* phase, the designer presents the prototype within the context of the user where it is meant to function. The prototype can be refined or changed depending on the outcome in the *test* phase. Any of the phases can be repeated as needed. Key themes presented in the d.school definition are reflected in several scholars' perspectives on design thinking in the literature.

2.2.1 Human-centeredness, Empathy, and the Social Context

The first phase, *empathy*, draws upon the concept of being human-centered and taking social contexts into account. Bucciarelli specifically highlights that design thinking relies on a social context because it requires interaction between individuals and collaboration between people [14]. Further, Zoltowski, Oakes, & Cardella specified that a key aspect of design thinking is "understanding the people affected by the design" [15]. Searching for and mitigating the negative effects of a design on its user is a step toward empathic design, where the user's feelings are a factor in development [16]. The synthesis of the multiple definitions in the literature provides emphasis that design thinking should thrive when multiple individuals, especially the users of the design, are involved and the social context is acknowledged.

2.2.2 Inquiry, Exploration, and Complex Cognitive Processes

Dym, Agogino, Ozgur, Frey and Leifer contend that design thinking "reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process, and "speaking" several languages with each other (and to themselves)" [17]. Yilmaz and Daly explain the complex cognitive processes involved through an in-depth exploration of a problem and possible solutions accompanied by thorough development and evaluation of potential solution pathways [18]. Like general design processes, a key aspect of design thinking is exploring multiple ideas through a process of inquiry that activates complex cognitive processes.

2.2.3 Iteration, Repetition, and Persistence

Brockman, Navoa, Svarovsky and Kloser emphasize that design thinking is "a prescriptive theory of design" and "a practical approach to effectively determining the needs for a design and iteratively developing a working prototype" [19]. Razzouk and Shute summarized perspectives from the literature and found frequent uses of descriptors like "iterative" and "non-linear" [5]. The theme of iteration, going back and forth through a series of steps in the process of understanding a problem and finding the most viable solution is an integral part of design thinking.

2.2.4 Communication, Representation, and Elaboration

Razzouk and Shute also from their findings in the literature, assert that design thinking deals with the representation of problem-solving concepts or ideas and drawing relations between ideas [5]. The process begins with a cloudy idea, leading to the creation of sketches and models to make ideas more concrete, followed by expressing the ideas with words to elaborate on them. Other researchers have highlighted reflective practices such as verbal expression and description of what students know about design in their disciplines as those relevant to design thinking [20, 21]. These verbal expressions and descriptions draw attention to the need for designers to communicate their ideas in a design process.

In addition to perspectives in the literature on what design thinking is, some scholars have also discussed what characteristics design thinkers should have, which can be useful in defining design thinking. Razzouk and Shute highlighted characteristics of design thinkers including that they are human- and environment-centered, able to visualize, predisposed to think about multiple solutions and able to pay attention to the big picture while simultaneously focusing on details (multifunctionality), capable of systemic vision, able to use language as a tool, able to work in teams and not fixated on one choice [5]. Brown also highlighted similar, but more nuanced, characteristics to look for in design thinkers including empathy, integrative thinking, optimism, experimentalism, and collaboration [10]. It is important to note that, although not all scholars that mention design thinking mean the same thing, most agree on the centrality of *empathy* in the process [22].

2.3 How Research on Teaching and Learning Informs Design Thinking

Design thinking has been shown to support a broad set of important learning objectives that are not easily addressed in a traditional engineering curriculum. Learning experiences that incorporate inductive learning, such as the practice of design thinking, promote deeper learning and transfer of knowledge gained to other contexts [23–28]. Inductive learning implies that a learner begins with something specific to address – problem to solve – which then leads to a need to explore the resources to solve the problem, thereby facilitating learning [27]. As we consider how to help students develop professional skills, it is worthwhile to note that social, emotional and intellectual factors affect the development of college-aged students [29–31].

2.4 Need for a Design Thinking Course

The incorporation of design thinking methods could provide an approach to address a broader set of learning outcomes within a resource constrained educational environment in engineering programs. The competitiveness of the United States, which is linked to standard of living, is dependent on our ability to produce a sufficient number of innovative engineers to meet the market demand [2, 32, 33]. Serious concerns have been raised about whether the U.S. is adequately preparing the next generation for the demands of an increasingly high-tech and interdisciplinary workplace, and whether enough scientists, engineers, and highly skilled workers are being produced [2, 32]. One of the critical aspects that is often ignored for the sake of more traditional curriculum content is nurturing the creativity of students - creativity that our students need to tackle the problems of today and tomorrow. This is generally a result of constraints in instructional capacity where programs have limited resources to apply towards electives when they are struggling to support required courses. When design thinking is used as an educational tool, our graduates can be actively engaged in the practical application of the engineering profession and can be empowered to embrace innovation. Design thinking is a methodology that fills the full spectrum of innovation activities with a human-centered design philosophy [10]. If trained for thorough understanding, direct observation of what people need in their lives, and what they like and dislike about how particular products are made, packaged, sold, and supported, our graduates, in collaboration with others, will be equipped to help communities globally to achieve their aspirations in creative yet responsible and sustainable ways [34]. Teaching students to be empathic, to have integrative thinking, optimism, experimentalism, and to be collaborative is to engage them in the five elements of the personality profile of a design thinker [10]. Used as an educational tool, design thinking methodology, also offers students an experiential learning environment that is open and encourages creativity.

Traditional design courses in most engineering undergraduate curricula focus on the design of artifacts with the consideration only of the functional properties of human-made artifacts. However, the functional properties are determined by the mental activity of their producers and users [35]. Furthermore, educators in most undergraduate engineering courses often have students solve problems that are well defined, with the dimensions, materials, forces, etc., being specified. However, in the world of practice, our students will encounter problems that are ill-structured [36]. Addressing this traditional educational environment provides an opportunity to expand and broaden learning opportunities for engineering students through the application of a design thinking methodology into a traditional undergraduate curriculum and limit the need to increase instructional resources.

Applying design thinking as a methodology and an educational tool further provides an opportunity for students to learn how to develop design thinking ability to tackle ill-structured problems through an authentic, immersive design experience that starts with the user in mind, and it is situated in culture and context (inspiration and ideation) [11, 37]. A design thinking course experience involves learning what to make and prototyping the idea early in the process (quick implementation). Students learn to design *with* the user, rather than *for* the user, as the user's role shifts from consumption to participation [38]. Engineering educators need to rise to the challenge of equipping students with foundational math and science skills and ensuring that they can use their skills to address novel and complex problems and challenges successfully. Most recent government reports and prioritized in the updated ABET outcomes challenge the engineering education curriculum to be anchored in mathematics and sciences, while emphasizing the professional role of the engineer and demanding new competencies suited for newly emerging world contexts, with innovation, interdisciplinarity and complex problems being a central theme [39–41].

There are several ways that design thinking can be used in undergraduate programs, as it is an approach not unique to engineering, but is one that cuts across academic disciplines [7]. Design thinking is a tool which can build one's creative confidence in a manner that is not restricted to a particular discipline. In fact, the literature provides examples where the approach has been implemented successfully.

2.5 *Aspirational Peer Programs*

Educators in engineering design have focused on developing courses that foster design thinking as a way of tackling problems [6]. For example, Melles, Howard, & Thompson-Whiteside discuss a design thinking course offered to students pursuing a design management minor [42]. The course was also offered as an elective to design students in various disciplines including in industrial design, interior design, and communication. Some engineering courses have also been taught using design thinking as a framework. An example is a software engineering capstone course as discussed by Palacin-Silver et al. [43]. The common examples of how design thinking has been used in undergraduate programs is by incorporating it into courses and other non-curricular design experiences [19, 12]. The courses involve exposing students to the design thinking process and engaging them in design activities that build on this exposure. A notable example is a co-design experience and performance, "Wild sound" that involved a multidisciplinary team including a composer, performers, and student engineers [19].

Guided by current best practices in design education to address the need for engineers of the desired caliber, we created a design thinking course based on contents adapted from the most well-established design programs and documented the observations and challenges faced from an instructor and administrative perspective. In the next section, we present the course, including students' work, learning outcomes, and our instructional approach. In the following section, we discuss the lessons learned, and challenges faced in the course implementation. We share insights from an instructor's perspective to facilitate adaptive course design and implementation of successful learning modules from well-established institutions. We also present administrative challenges in implementing design thinking effectively in a constrained curriculum.

2.6 *Summary of Literature Review*

Literature regarding the specific practice of Design Thinking has become a significant area of study over the last 20 years. It was conceived as a modern approach to design with an emphasis on empathy with the stakeholder and has evolved to become a pedagogical approach to improve student motivation, purpose driven creativity and deep thinking. This literature review describes several points of this evolution and then connects the practice of Design Thinking with appropriate teaching and learning methods. The ability to use Design Thinking as a tool to achieve broader and more difficult learning outcomes is presented along with examples of institutions that are currently using Design Thinking in their curriculum. Using this starting point, this literature review sets the stage for the motivation and process of implementing Design Thinking into an undergraduate engineering course in a resource constrained program. Following educator and administrator reflections will provide further context in understanding the challenges and rewards of incorporating a Design Thinking approach.

3. Case Study: Course Design

This course was an elective course developed at a resource constrained institution for students in multiple engineering programs. In this course, students work individually to apply design thinking methods on a toy design project for concept generation, product definition, prototyping, and empathic and verification design. Based on the main goals of the course, we have divided our description of the course into three sections.

Students enrolled in the course were undergraduate and graduate students majoring in engineering as the course was open to both undergraduate and graduate students. Nineteen students enrolled in the class after advertising through the College of Engineering. Twelve students were seniors and seven were graduate students in the first semester of their master's degree studies. The majority of the students were from mechanical engineering, five were from aerospace engineering, and one was an electrical engineering student. The class met twice a week for a seventy-five-minute session.

3.1 Learning Outcomes

The course explored design thinking through the five-phase process: *empathy*, *define*, *ideate*, *prototype*, *test* [13]. The focus was on learning 'to design', "design tools", and 'design processes' with a toy prototype as a course project. The design of artifacts was addressed from a multidisciplinary perspective. The methodologies covered understanding and defining opportunities for innovation, developing, and producing globally competitive products. The course topics went beyond addressing functions and focused on critical thinking and innovation to design and develop products with user experience in mind.

Based on the course focus described above, we adopted the following learning outcome: At the end of the course, students will be able to apply the design thinking methodology as seen in their toy design using inspiration-ideation-imagination-iteration-implementation. The overall learning outcome of applying the design thinking methodology was complemented by focusing experiences on the fundamentals of product design and ideation, concept generation techniques, and sketching for design communication.

3.2 Instructional Approach

The course was designed with the following principles: (1) provide students with an environment that is open and encourages creativity, (2) provide an authentic and immersive design experience on empathic design and related topics, and (3) generate student, faculty, and community interest to ensure sustainability of the course.

3.2.1 Class Features

The class structure was modified to use the concept of learning community – students needed to engage with others in the course, although each had individual assignments and projects. The students led discussions on different topics. The approach encouraged collaborative and cooperative learning. To foster creativity: (1) design reviews of projects were done several times as a whole group, and (2) sketching exercises were done in class.

The students were treated as junior engineers within a company, empowered to learn through doing. The toy design project given was vague on purpose, as to reflect real-world practice. The ambiguity forced the students to make and justify engineering decisions on how to proceed with the project. The design of an artifact was addressed from the design thinking framework perspective including opportunity determination through inspiration, ideation, and implementation. The course methodologies were covered first were understanding and defining opportunities for innovation, and second, developing and producing globally competitive products. The students individually applied their knowledge from the course on the toy design project. Through the semester students met with the potential "users of their designs" for initial, immediate, and quick feedback. The "toy" users were local school children (age 5 to 12), who engaged in two design sessions. The students created blueprints for their design, a prototype of the toy, and an informational poster about their artifact. At the end of the semester, the students hosted a Toy Fair for others to view their toys and to meet with the designers. The toys along with their posters and the designers' biographies were on display in the main lobby of the University Library for three months, where anyone from the University and the town's community, including students from the local elementary schools can view.

3.2.2 Course Activities

The course learning materials and activities were selected based on the idea that design thinking is not a method restricted to engineering and architecture but is one that can be used in various contexts where solving problems or meeting needs is a point of concern [10]. Therefore, all learning materials and course activities were chosen from seminal work, related to the core principles of design thinking philosophy [44–64]. In the course project, students worked individually to apply the methods on a toy design project for concept generation, product definition, prototyping and empathic and verification design. The toy design provided a scaffold for students to learn the design process holistically. The course was neither concentrated on CAD techniques nor design for functionality, manufacturing, assembly, and other areas that are typical of many design courses. The students were expected to be fluent in CAD. The lectures and workshops directly contributed to the toy design, inspiring students to enjoy and have fun in this class while they learn how to engage with the user of their creations through empathy. Lecture-by-lecture topics are provided in the Appendix along with the associated assignments.

3.2.3 Assessment

The main assessment instrument for the course was a toy design report rubric to evaluate an artifact of the students' performance in the course, the toy design report. To contextualize the rubric, the report will be described first. The toy design report needed to begin with the proposed toy and the inspiration for the design, followed by a visual representation of the student's design. The steps of ideation were also asked to be included to outline their steps of concept generation – including sketching, storyboarding, and diagramming – and how their observations of the user changed their design. CAD-work, sketch-work, and other drawings were expected to be appended to the report.

After the description of the development of the toy, the functionality needed to be outlined. Virtual prototyping of the toy and functional decomposition of the implementation were required. Plans for additive manufacturing were expected. Also, the students needed to provide suggestions for how the toy could be used for educational purposes. Finally, safety instructions for the use of the toy and notes to the user were needed to close the report.

A standard three level rubric (0,1,2) with seven criteria was adapted from Bairaktarova, Bernstein, Reid and Ramani [65] to assess performance on the toy design report (Table 1). The rubric created to assess the student artifacts was intentionally tied to the five elements of design thinking: *empathize, define, ideate, prototype*, and *test*. Empathic design was considered as a dimension of the rubric to underscore the philosophy of design thinking. General presentation and organization of the report was factored into the overall score as well.

Awards were given for excellence in visual thinking, novelty in design, and overall best design (1st, 2nd, and 3rd places). The winners were selected anonymously from all students in the class.

3.2.4 Sample Work

The examples in Figs. 1, 2 and 3 present students *design thinking* experiences through physical artifacts while engaged in the ideation (freehand sketches), inspiration (notes on understanding the user and getting into their shoes), and implementa-

Table 1. Rubric for Design Report

Dimension	Points		
	2	1	0
Ability to recognize user needs and product requirements using appropriate methods and frameworks (14%)	Extensive analysis and research on the user environment	Limited analysis and research on the user environment	None of the appropriate tools/ methods were used to meet this topic
Ability to identify inspire, and ideate potential concepts (14%)	Extensive use of Morphology Chart, Functional Decomposition, Storytelling	Limited use of Morphology Chart, Functional Decomposition, Storytelling	Lack of Morphology Chart, Functional Decomposition, Storytelling
Effectiveness in using methods related to visual thinking throughout the design process (15%)	Extensive use of Sketching, Storyboarding, Diagramming	Limited use of Sketching, Storyboarding, Diagramming	Lack of Sketching, Storyboarding, Diagramming
Feasibility of the final design (manufacturability, deployment, and use) (14%)	Extensive consideration for manufacturability and deployment	Limited consideration for manufacturability and deployment	Lack of consideration for manufacturability and deployment
Effectiveness in communicating ideas, concepts, strategies (15%)	Contains representations of abstract Prototyping, Virtual Prototyping, Proof-of-concept, CAD work, Detailed Drawing	Poor representations of Abstract Prototyping, Virtual Prototyping, Proof-of-concept, CAD work, Detailed Drawing	Lacking Abstract Prototyping, Virtual Prototyping, Proof-of-concept, CAD work, Detailed Drawing
Presentation and organization (14%)	Writing is clear and logically organized	Writing contains distracting errors or is not logically organized	Writing contains distracting errors and is not logically organized
Practice Empathic design (14%)	Report details empathic inferences about users and their possible futures.	Report communicates limited empathic inferences about users and their possible futures	Report does not include empathic inferences about users and their possible futures

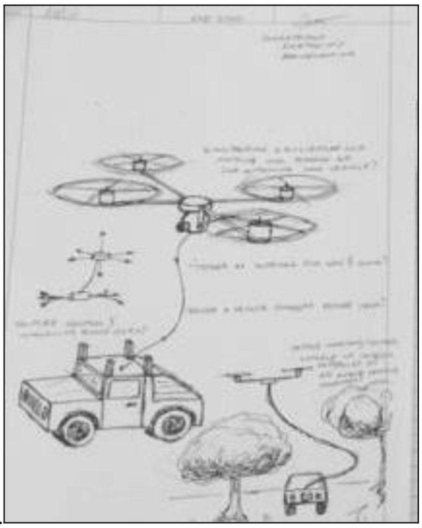
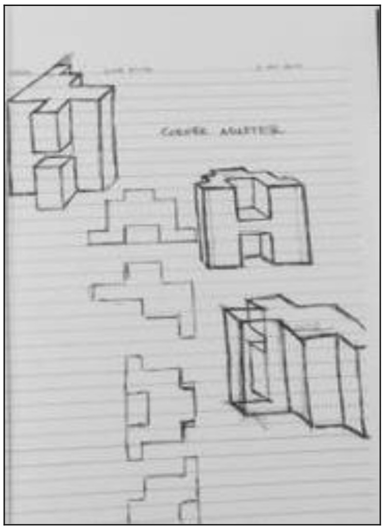
1a.  1b. 

Fig. 1. Examples of *ideation* phase of design thinking process: 1a. Freehand sketching in storyboard to explore the user environment; 1b. Freehand sketching in concept generation.

Notes: Steps in the Design Process
Product Design Process with "*Systematic Innovation*"
Deliver new value to your customers
Understanding your customers better than they understand themselves

Look beyond what the customers tell you

EXERCISE: Reading between the signs

- Interviewer has to 1) gauge their emotions, 2) determine what most excites them about product, 3) determine what most disenchants them about product
- After interview, Lucas or I will get class's feedback. What did you see? Was it easy to pick out? What's the takeaway from this exercise?
- PP1: You are an elderly man/woman, who doesn't understand high-tech, sophisticated product features very well. You prefer simplicity and ease-of-use in your products.
- PP2: You are a 6-year old boy/girl. You don't care if it works or if it doesn't; you just care about the COOL factor (colors, sounds, moving parts, high-tech).

Performance needs, Basic needs, and Excitement needs

- Several tools that can be used (CAGE, VOC, Kano)
- **Analyzing the situation**
  - **Understand the problem**
  - **Clarify the project scope**
  - **Look for existing solutions**
  - **If you can't solve A, can you solve B or C to make the solution to A unnecessary?**
  - **Anticipate future problems**
- Choosing idea generation/problem solving tool
  - The "right" idea generation tool depends on the situation
- Idea generation
  - Tools:

Fig. 2. Examples of the *inspiration* phase of design thinking process: student's notes.

tion (the user's stories presented in the posters and 3D printed prototypes) stages of the toy design.

4. Challenges Faced and Lessons Learned

Looking at the five elements of the design thinking – *empathize, define, ideate, prototype*, and *test* – we aimed students to learn how to focus on the user, on the human experience, involving the user in the design process, and quickly prototyping for innovation. With the toy design project, we believe we achieved the learning goals for the course. This course was not about CAD skills, neither manufacturing nor perfection of the prototypes. The technical content such as 3D printing was for students to go through the whole process of design thinking using the available resources. The specific reflections on the overall course implemen-

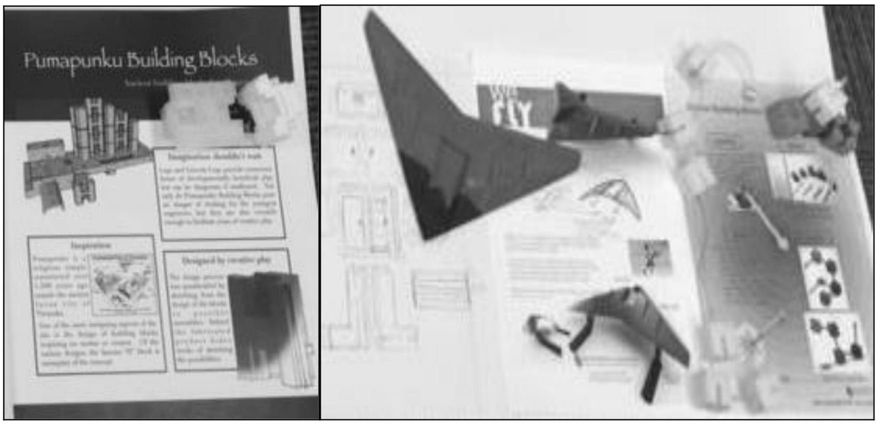


Fig. 3. Examples of the *implementation* phase of design thinking process: the physical artifacts.

tation were grouped into instructor specific comments and broader administrative perspectives and presented below.

4.1 Instructor's Reflections

Following the course delivery, several cogent questions and concerns were noted by the instructor. These questions were centered around course resources which reflected on the student's motivation. Instructor resources are critical for a design thinking course. Students need to have a minimal opportunity to fabricate a reasonable prototype to participate in the process. The fabrication tools do not need to be state of the art but should provide the ability to create a design. Instructors who teach such courses might ask: *What kind of institutional support is there, if any?; Do engineering design educators in small engineering programs are empowered to promote and enhance design thinking education?; How do we convey to our engineering students that engineering is not all about the technical skills they learn in college?* These questions are probably a larger problem overall. The ability to portray relevance is critical for any engineering course. A design course like the one described here could be part of the solution to this larger problem.

How can we convey that the ability and the opportunity to improve people's lives are privileges that require an understanding of human behavior, trial and error, failure, and in many occasions dealing with constraints we do not have control over? Further, the need to embrace failure aligns with the mindfulness perspective that differs from the typical engineering course where finding the appropriate right answer is critical. Including mindfulness workshops or stand-alone courses on mindfulness might be the solution. How do we convey to students that working in a learning community with a resource constrained environment moves novice designers to experts and mediocre designers to great designers?

4.1.1 Students' Motivation

Throughout the semester, we partially addressed some of the student motivation issues by creating a learning environment with discussion type instruction and enabled students to explore their creativity. We also invited local guest speakers from different disciplines including art and architecture. We utilized different instructional methods to convey the idea of design thinking philosophy better and motivate students to look at design as a space, not a step-by-step procedure.

With the limited resources available for the course, the 3D printed parts were printed poorly. In many instances, design components did not reflect the models developed by the students. Students wished that the prototypes of their designs could have been printed at a higher resolution at a lower scaling ratio and still been ready for the toy fair. Some of the students stopped trying to fix their parts after multiple hours of trying to make the parts look, in their opinion, acceptable. As one of the students shared: "*One part has broken under minimal force and left my toy incomplete. I am enrolled in another manufacturing class and if I were to say that a single one of the parts was acceptable, I would receive a failing grade*". Facility and equipment constraints needed special attention from the instructor to ensure that it was not demotivating the students. Including topics on 3D printing and prototyping in such a course could add value to students so that they can consider the limitations of the capabilities when building the prototypes. At the same time, engineers always struggle with the limitations of fabrication technology, and this is a normal "real world" challenge that is being presented in this course context. Working within the constraints of budget and schedule are integral to every design process and does not detract from the design thinking methodology learning objectives.

Use of the external design reviews reduced the instructional assessment load. Regarding the use of sketching in class, free-flowing idea generation sessions were beneficial for students to generate toy ideas without thinking about the functions of the artifacts. The students were also enthusiastic about leading the discussion sessions and the ability to be involved in the instructional process. A student group of two was responsible for presenting a lecture topic through the semester. All students participated in this active learning approach and had engaging discussions on the topics assigned.

4.1.2 Design Fixation

In some instances, students were not able to generate and explore different toy concepts, because of idea fixation. Educators can consider inviting designers from different disciplines to explore ideation and to help students overcome idea fixation. The instructor could ask guest lecturers from architecture and arts (fine artists and musicians) to discuss creativity from a different perspective. In certain cases, during student-led discussions, the activities became the focus rather than the topic. To address the challenge, instructors could start with a short presentation at the beginning of each topic, where the instructor highlights the important points before students lead a discussion and learning activities.

Interactions with the intended users were helpful in refining the concepts. Most students took an ad-hoc approach to integrate the information gained from observing user interactions and interviews. The student designers also tried to include design for manufacturing, modularity, and design for reuse. Students applied some of the user experience concepts when designing the toys. In most instances, the concepts were applied at a superficial level. The students were more focused on the aesthetics of the artifact, rather than designing the toy to address different users' perspectives. To address this challenge, educators can ask the students to directly apply more of the pertinent course topics as students move along the semester on their artifact design.

4.1.3 Toy Fair

At the end of the semester, we invited not just the university community, but also the public. We encouraged everyone to engage in conversations about design thinking. We hoped for our students to learn how to focus on the user, on the human experience, involving the user in the design process and quickly prototyping for innovation. Further, we looked to engage the local community in current conversations and trends in design thinking. We wanted to expose people to the idea that we strive to educate engineers who are not only creators of physical objects, processes, and systems, but engineers who are trained to improve people's lives, with the understanding of human experience and behavior.

Students were excited to get the 3D printed prototype of their toy design. The excitement of the students also energized others in the University. The library authorities eagerly anticipated for people to see the ingenuity and creativity of the engineering students, and they looked forward to advancing the conversation around how making and engineering with digital fabrication tools enables the testing of creative and innovative ideas. University officials also hoped to keep the toys on display during a local TED conference to encourage collaboration and support for the Innovation Hub tent being planned at that time. Those who visited the toy exhibit shared the enjoyment of talking to the student-designers and witnessing their excitement. The library leadership were hoping to host more of these types of events and to use the momentum the students from the design thinking class created to fuel the appetite and usage of the Innovation Hub where even bigger ideas will be possible.

4.2 Administrator's Reflections

Design courses are an integral and required part of any accredited engineering program. The capstone design courses in each program are typically structured to deliver and assess many of the non-technical, but increasingly critical ABET outcomes noted above. The last has typically produced mixed results that do not fully address the outcomes but are more efficient for resource constrained institutions. Many smaller engineering programs have a limited ability to offer multiple elective courses due to instructional capacity constraints (lack of available and competent instructors) and the need to offer electives that support a wide range of potential student career interests. Small programs have limited ability to devote instructional resources to specific design approaches that address intangibles such as creativity and innovation skills in required courses regardless of the critical need for these skills. Resource constrained programs are attempting to maintain a balance between instructional capacity and the identified needs for student competencies. Most curriculums are designed to allow students a balance between a flexibility to achieve a wide variety of desired competencies and achieving the competencies deemed required by program faculty and stakeholders. Bringing the competency of creativity fully into a traditional curriculum would require incorporating it into existing required design courses or eliminating other perceived required competencies.

Instructional capacity in design courses is additionally constrained due to the nature of the course structure. The individual nature of the design review for a variety of correct solutions to a particular problem requires a more holistic instruction and assessment process by the instructor as noted by the implementation of the process-oriented rubric. This is highly effective for individual students but requires a significantly higher workload investment by the instructor. As such, these courses typically require a restricted enrollment to maintain a balanced instructor workload and are more applicable to elective courses. Broadly expanding this technique into the required design curriculum of a small engineering program will require an investment in teaching assistants or a highly modularized assessment approach that can achieve the same level of interaction as an individual in a small course.

In addition to instructional capacity, resource constrained institutions have a limited ability to provide student fabrication resources to complete the *prototype* phase of the Design Thinking process. Many institutions have a limited ability for students to access tools and materials to fabricate their designs. Manifesting a physical prototype is an integral phase of the design thinking process and must be available for students to achieve the complete set of learning outcomes. At the same time, attainment of the learning outcomes does not require state of the art fabrication resources. In fact, achieving a representative prototype using constrained fabrication tools provides students an insight into real-world constraints. Creative instructors can build these constraints into a more effective learning environment for students. Overall, there are several administrative challenges in implementing design thinking methodologies in a resource constrained environment.

5. Conclusions

This article described a design thinking course implemented to enable students to apply the design thinking methodology. The course centered around the development of a toy design using empathic techniques to be displayed in a culminating public forum. Reflections from both educator and administrator were shared to provide insight into effective approaches and the challenges to be overcome in effectively implementing a course based on design thinking philosophy. Based on educator reflections, it is clear that generating and maintaining student motivation for design thinking is a critical factor in the success of the course. The ability to link projects to an impactful event such as a toy fair can be useful in developing this motivation. At the same time, student expectations must be managed throughout the course. In some cases, students expect to produce the perfect prototype on the first attempt, thus it is important to reinforce with students that this process is inherently iterative and most early prototypes will not be perfect. In fact, limitations in prototype fabrication could illustrate deeper learning by exposing a student to the more vital elements of an effective design. In addition to fabrication, real world assessment methods are critical for student engagement and growth. Design thinking is inherently process driven and is not tied to a specific correct answer. The effective use of assessment rubrics can help guide students through this process. Lastly, the design thinking approach reinforces the intellectual balance between applying creative solutions and alignment with a stakeholder. The method further teaches students to be more empathetic by aligning design with the customer's needs rather than focus on their own personal knowledge and beliefs. The design thinking approach provides an effective pedagogical framework to achieving challenging behavioral learning goals related to empathy, aligning with a stakeholder and purpose driven motivation.

Adopting a design thinking approach requires a balance between instructional resource availability and attaining appropriate learning objectives. Employing a design thinking methodology throughout a design curriculum can better support broader learning outcomes. In engineering, these outcomes are an essential element of the accreditation process and ensures the development of well-rounded engineers. A design thinking approach may also generate a significant increase in instructional workload for the educator and associated program administrator. Implementing a design thinking course is clearly resource intensive due to the higher coordination and assessment load. Aligning design thinking methodology with existing required courses in the curriculum and creatively enlisting other available institutional resources could reduce this workload for resource constrained institutions. Implementation of design thinking into a course requires a dedicated instructor but the initial development can be substantially minimized through use of relevant literature and a structured implementation. The outline of the design thinking approach described in this paper provides an effective starting point for developing a structure and implementing a new course based on design thinking methodology. Future work involves further refinement to the course and comprehensive assessment data to answer pending empirical research questions on the efficacy of such learning opportunity. Next steps will be to design a research study to investigate (1) the students' perceptions, and (2) to provide evidence of the enhancement of students' design thinking skills, particularly creativity and empathy.

References

1. J. Walther, N. W. Sochacka and S. E. Miller, *Empathy in engineering: Why it's important, and what we are doing about it*. National Science Foundation (NSF) Engineering Education and Centers (EEC) Grantees Conference, Washington D.C., 2017.
2. National Academy of Engineering, *The engineer of 2020: Visions of engineering in the new century*, National Academies Press, Washington, D.C., 2004.
3. Accreditation Board for Engineering and Technology (ABET) website, *Criteria for Accrediting Engineering Programs, 2020–2021*, https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/, Accessed April 2021.
4. L. J. Shuman, M. Besterfield-Sacre and J. McGourty, The ABET "professional skills" – Can they be taught? Can they be assessed?, *Journal of Engineering Education*, **94**(1) pp. 41–55, 2005.
5. R. Razzouk and V. Shute, What is design thinking and why is it important?, *Review of Educational Research*, **82**(3) pp. 330–348, 2012.
6. T. Brown and J. Wyatt, (2010), Design thinking for social innovation, *Development Outreach*, **12**(1), pp. 29–43, 2010.
7. M. Camacho, David Kelley: From design to design thinking at Stanford and IDEO, *She Ji: The Journal of Design, Economics, and Innovation*, **2**(1), pp. 88–101, 2016.
8. M. Gobble, Design thinking, *Research-Technology Management*, **57**(3), pp. 59–62, 2014.
9. P. Rodgers, Articulating design thinking, *Design Studies*, **34**(4), pp. 433–437, 2013.
10. T. Brown, Design Thinking, *Harvard Business Review*, June 2008.
11. T. Brown, *Change by Design: How Design Thinking Transforms and Inspires Innovations*, Harper Business, New York, NY, 2009.
12. G. Chao, What is Design Thinking?, *The Stanford Daily*, May 2015.
13. Stanford d.school website, https://dschool.stanford.edu/ Accessed October 2021.
14. L. Bucciarelli, Design knowing & learning: A socially mediated activity, in *Design knowing and learning: Cognition in design education*, Elsevier Science, pp. 297–314, 2001.
15. C. Zoltowski, W. C. Oakes and M. E. Cardella, Students' ways of experiencing human-centered design, *Journal of Engineering Education*, **101**(1), pp. 28–59, 2012.
16. L. Crossley, Building emotions in design, *The Design Journal*, **6**(3), pp. 35–45, 2003.
17. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey and L. J. Leifer, Engineering design thinking, teaching, and learning, *Journal of Engineering Education*, **94**(1), pp. 103–120, 2005.
18. S. Yilmaz and S. R. Daly, Feedback in concept development: Comparing design disciplines, *Design Studies*, **45**(A), pp. 137–158, 2016.
19. J. B. Brockman, G. N. Svarovsky and M. Kloser, Making "Wild Sound": A Case Study in Engineering and Musical Performance Co-design, In *2015 ASEE Annual Conference & Exposition*, Seattle, WA, 2015.
20. J. G. Knowles, T. Kelley, E. Sung and J. Choi, Research Design, Data Collection, and Assessment Methods for an Integrated STEM Education Model (Work in Progress), In *2017 ASEE Annual Conference & Exposition*, Columbus, OH, 2017.
21. D. Richter, M. Paretti, L. McNair and M. Borrego, Assessing Student Perspectives of Interdisciplinary Collaboration, In *2009 Annual Conference & Exposition*, Austin, TX, 2009.
22. G. Goldschmidt, and P. A. Rodgers, The design thinking approaches of three different groups of designers based on self-reports, *Design Studies*, **34**(4), pp. 454–471, 2013.
23. A. Johri, B. M. Olds and K. O'Connor, Situative frameworks for engineering learning research, in *Cambridge handbook of engineering education research*, Cambridge University Press, pp. 47–66, 2014.
24. T. Litzinger, L. R. Lattuca, R. Hadgraft and W. Newstetter, Engineering education and the development of expertise, *Journal of Engineering Education*, **100**(1), pp. 123–150, 2011.
25. W. Pan and J. Allison, Exploring project based and problem-based learning in environmental building education by integrating critical thinking, *The International Journal of Engineering Education*, **26**(3), pp. 547–553, 2010.
26. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**(3), pp. 223–231, 2004.
27. M. Prince and R. M. Felder, Inductive teaching and learning methods: Definitions, comparisons, and research bases, *Journal of Engineering Education*, **95**(2), pp. 123–138, 2006.
28. A. J. Withell and N. Haigh, Developing design thinking expertise in higher education, in *The 2nd International Conference for Design Education Researchers, Design Learning for Tomorrow*, Oslo, Norway 2013.
29. J. Adler, Review of The Meaning of Things: Domestic Symbols and the Self, by M. Csikszentmihalyi and E. Rochberg-Halton, *Contemporary Sociology*, **12**(4), pp. 452–453, 1983.
30. L. H. Jamieson and J. R. Lohmann, Creating a culture for scholarly and systematic innovation in engineering education: Ensuring US engineering has the right people with the right talent for a global society, Report for *American Society for Engineering Education*, Washington, DC, 2009.
31. D. S. Yeager, and C. S. Dweck, Mindsets that promote resilience: When students believe that personal characteristics can be developed, *Educational Psychologist*, **47**(4), pp. 302–314, 2012.
32. National Academy of Engineering, *Educating the engineer of 2020: Adapting engineering education to the new century,* Washington, D.C., National Academies Press, 2005.
33. S. D. Sheppard, K. Macatangay, A. Colby and W. M. Sullivan, *Educating Engineers: Designing for the future of the field*, Jossey-Bass, San Francisco, CA, 2009.
34. M. Kouprie and F. S. Visser, A framework for empathy in design: stepping into and out of the user's life, *Journal of Engineering Design*, **20**(5), pp. 243–448, 2009.
35. L. R. Baker, On the twofold nature of artefacts, *Studies in the History and Philosophy of Science Part A*, **37**(1), pp. 132–136, 2006.
36. D. Jonassen, J. Strobel and C. B. Lee, Everyday problem solving in engineering: lessons for engineering educators, *Journal of Engineering Education*, **95**(2), pp. 139–151, 2006.

37. T. Kelly and J. Littman, *The Ten Facets of Innovation: IDEO's Strategies for Defeating the Devil's Advocate and Driving Creativity Throughout Your Organization*, Random House, New York, NY, 2005.
38. J. Liedtka and H. Mintzberg, Time for Design, *Design Management Review*, **17**(2), pp. 10–18, 2006.
39. M. Allan and C. Chisholm, Achieving engineering competencies in the global information society through the integration of on-campus and workplace environments, *Industry and Higher Education*, **22**(3), pp. 145–152, 2008.
40. J. Earnest and S. Hills, ABET Engineering Technology Criteria and Competency Based Engineering Education, In *35th ASEE/IEEE Frontiers in Education Conference*, Indianapolis, IN, 2005.
41. F. T. Evers, *The bases of competence: Skills Portfolio Specifications*, University of Guelph, Guelph, Ontario, 2005.
42. G. Melles, Z. Howard and S. Thompson-Whiteside, Teaching design thinking: Expanding horizons in design education, *Procedia-Social and Behavioral Sciences*, **31**, pp. 162–166, 2012.
43. M. Palacin-Silva, J. Khakurel, A. Happonen, T. Hynninen and J. Porras, Infusing design thinking into a software engineering capstone course, In *2017 IEEE 30th Conference on Software Engineering Education and Training*, Savannah, GA, 2017.
44. H. Dubberly and S. Evenson, The analysis-synthesis bridge model, *Interactions*, **15**(2), pp. 57–61, 2008.
45. G. Pahl and W. Beitz, *Engineering Design: A Systematic Approach*, Springer, 2007.
46. D. G. Ullman, *The Mechanical Design Process*, McGraw–Hill, 1992.
47. M. W. Johnson, The White Space and Business Model Innovation: Finding Brilliant Opportunities Outside Your Core, in *Seizing the White Space: Business Model Innovation for Growth and Renewal*, Harvard Business Publishing, Boston, MA, 2010.
48. M. Eyring, M. Johnson and H. B. Nair, New business models in emerging markets, *IEEE Engineering Management Review*, **42**, pp. 19-26, 2014.
49. U. Ibusuki and P. C. Kaminski, Product development process with focus on value engineering and target-costing: A case study in an automotive company, *International Journal of Production Economics*, **105**(2), pp. 459–474, 2007.
50. K. J. Stephen, Integrating Value Engineering into the Design Process, *Ekistics*, **56**(336/337), pp. 166–70, 1989.
51. R. Nidumolu, C. K. Prahalad and M. R. Rangaswami, Why Sustainability Is Now the Key Driver of Innovation, *IEEE Engineering Management Review*, **41**, pp. 30–37, 2013.
52. R. Verganty, *Interpreting: Developing Your Own Vision–The All-Important Research Phase of Design-Driven Innovation*, Harvard Business Review Press, Boston, MA, 2009.
53. J. H. Dyer, H. B. Gregersen and C. M. Christensen, *The Innovator's DNA: Mastering the Five Skills of Disruptive Innovators*, Harvard Business Press, Boston, MA, 2011.
54. R. H. McKim, *Experiences in Visual Thinking*, 2nd edition, PWS Engineering, Boston, MA, 1980.
55. G. Goldschmidt, On visual design thinking: the vis kids of architecture, *Design Studies*, **15**(2), pp. 158–174, 1994.
56. V. Goel, *Sketches of thought*, MIT Press, Cambridge, MA, 1995.
57. D. Ullman, S. Wood and C. David, The importance of drawing in the mechanical design process, *Computers & Graphics*, **14**, pp. 263–274, 1990.
58. M. Schütze, P. Sachse and A. Römer, Support value of sketching in the design process, *Research in Engineering Design*, **14**, pp. 89–97, 2003.
59. M. Yang, Observations on concept generation and sketching in engineering design, *Research in Engineering Design*, **20**, pp. 1–11, 2009.
60. W. C. Kim and R. Mauborgne, Blue ocean strategy, *Harvard Business Review*, **82**(10), pp. 76–84, 2004.
61. C. Prahalad and A. Hammond, Serving the World's Poor, Profitably, *Harvard Business Review*, **80**(9), pp. 48–59, 2002.
62. G. Boothroyd, P. Dewhurst, and W. A. Knight, *Product design for manufacture and assembly, 3rd ed*, CRC Press, Boca Raton, FL, 2010.
63. X. F. Zha and R. Sriram, Platform-Based Product Design and Development, *Knowledge Support Strategy and Implementation*, **19**(7), pp. 524–543, 2005.
64. M. Oliveira, I. Maia and J. Silva, Exploring the Capabilities of the Rapid Prototyping Technologies-SLS and FDM, In *6th Brazilian Congress on Manufacturing Engineering*, 2011.
65. D. Bairaktarova, W. Bernstein, T. Reid and K. Ramani, Beyond Surface Knowledge: An Exploration of How Empathic Design Techniques Enhances Engineers Understanding of Users' Needs, *International Journal of Engineering Education*, **32**(1A), pp. 1–12, 2016.

Diana Bairaktarova – MBA, PhD, is an Associate Professor in the Department of Engineering Education, an Affiliate faculty in the Department of Mechanical Engineering and the Human-Centered Design Program at Virginia Polytechnic Institute and State University. Diana has over a decade of experience working as a Design Engineer. She engages in research with undergraduate and graduate students, educators, and practitioners by doing research that crosses disciplines, including engineering, psychology, and the learning sciences; Her work encompasses three focus areas: learning environments; factors impacting student performance and creativity; ethical and empathic design. Bairaktarova translates her findings into practical pedagogical approaches by designing and applying contemporary learning environments that closely map the engineering work ethos.

Donald Plumlee – PE, PhD, is the Associate Dean for Academic Affairs in the College of Engineering and an Associate Professor in Mechanical and Biomedical Engineering at Boise State University. Donald completed his PhD in Mechanical Engineering from the University of Idaho, and he also holds a MS in Mechanical Engineering from Boise State University and a BS in Mechanical Engineering from Texas A&M University in College Station, TX. Donald has a decade of experience in the aerospace industry with Lockheed Martin Astronautics where he supported the Atlas/Centaur launch vehicle family used for commercial space access. Prior his current role, he served six years as Department Chair of the Mechanical and Biomedical Engineering department at Boise State University. His research includes the development of novel plasma medicine devices using Low Temperature Co-Fired Ceramics as well as engineering education research in design and creativity, particularly the connections between creativity and mindfulness.

Appendix

Schedule of Lectures and Activities

#	Lecture Topic	Related Readings (R), Videos (V), Assignments (A)
1	Introduction to the Course	Reading (R) 1: Time for Designing (Liedtka & Mintzberg, [38]) R2: Analysis-Synthesis Bridge model-Hugh Dubberly [44]
2	Design Thinking	R3: Design Thinking (Brown) [10] R4: Design Thinking for Social Innovation (Brown & Wyatt) [6] Video (V) 1: Tim Brown on Innovation V2: IDEO Shopping Cart
3	Steps in the Design Process	R5: Pahl and Beitz [45] or Ullman [46] V4: Product Design Process with Systematic Innovation
4	In-class Activity	
5	Identify Product Opportunities and Customer Requirements	R6: The White Space and Business Model Innovation (Johnson [47]) R7: New Business Models (Eyring, Johnson & Nair [48]) V4: Charles Leadbeater on user-centric design
6	Value Engineering	R8: Product development process with focus on value engineering and target-costing: A case study in an automotive company [49] R9: Think Value Engineering [50] V5: Value Engineering (Smith)
7	Innovation	R8: Sustainability is the key driver for innovation (Nidumolu & Parahalad [51]) R9: Interpreting (Verganti, Roberto [52]) R10: The Innovator's DNA (Dyer, Gregersen & Christensen [53])
8	Creativity through Play	
9	Storyboarding and Visual Thinking	R11: Experiences in visual thinking (McKim [54]) R12: On visual design thinking: the vis kids of architecture (Goldschmidt [55])
10	Sketching	R11: Sketches of thought (Goel [56]) R12: The importance of drawings in the mechanical design process (Ullman, et al. [57])
11	Sketching	R13: Support value of sketching in the design process (Schutze, et al. [58])
12	Concept Generation	R14: Concept generation and sketching (Yang [59])
13	Human Centered Design	R15: An Introduction to Human-centered design – Acumen
14	Empathic Design	R16: Blue Ocean Strategy (Kim & Mauborgne [60]) R17: Serving the world's poor (Prahalad & Hammond [61]) V5: Yves Behar on Designing objects that tell stories V6: Timothy Prestero on Design for people, not awards
15	Observation Assignment	
16	Guest Lecturer - Artist	
17	Material Selection	R17: Boothroyd and Dewhurst [62]
18	Design for Safety	
19	Product Platform and Family	R18: Chapter 1: Platform-Based Product Family Development Introduction and Overview [63]
20	Guest Lecture - Industrial Designer	
21	Rapid Prototyping	R19: Exploring the capabilities of the rapid prototyping Technologies - SLS and FDM [64]
22	Toy Dissection	
23	Guest Lecturer -Ethnography	
24	Work on Toy Design Project	A. Model of Prototype
25	Work on Toy Design Project	
26	Work on Toy Design Project	
27	Work on Toy Design Project	A. Final Submission of Report
28	Work on Toy Design Project	
29	Work on Toy Design Project	A. Final Submission of Prototype
30	Final Presentation	
31	Toy Fair – Public demo	