ABSTRACT

KIM, BYUNGSOO. Technology to Product Design Process (TPDP) for Design Education (Under the direction of Dr. Sharon Joines).

In this dissertation research, three studies were conducted to better understand how technology-driven design processes and skill sets are taught and mentored in Industrial Design (ID) education and the contemporary industry and to update existing design processes, methods, and tools that can help instructors to teach and guide ID students to become design practitioners who will actively contribute their design skills and creativity to technology organizations.

In Study 1, surveys and interviews were conducted with 55 ID educators, practitioners, students and novice industrial designers. The collected data led to the development of a Technology to Product Design Process (TPDP) model and identification of some of the methods and tools associated with TPDP.

In Study 2, two case studies were conducted with two Technology-Driven Organizations (TDOs). The synthesized results of the case studies were categorized as follows: 1) the role of designers in TDOs; 2) methods for increasing the contribution of design to these organizations; 3) designers’ challenges while working for TDOs; 4) methods and tools for technology-driven design projects; and 5) the future role of design in the 4th Industrial Revolution. The results of the study identified some design methods and tools associated with TPDP.

In Study 3, a total of 11 design experts (ID educators and practitioners) were recruited to evaluate the developed TPDP model and related tools. Semi-structured interviews were conducted to receive feedback, with nine different aspects to consider that were identified in previous studies. The experts’ feedback was synthesized to update the TPDP, methods, and tools.

The findings and insights combined from all three studies contribute to guiding how to teach and mentor ID students and novice designers within a technology-driven context.
Technology to Product Design Process (TPDP) for Design Education

by
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DEDICATION

I dedicate this dissertation to my parents, who prayed, supported and helped me in all things great and small.

This dissertation is also dedicated to my lovely wife, who supports me in pursuing my dreams and finishing my dissertation.

Thank you to Professor Sharon Joines, who not only guided me in this process and kept me on track, but also mentored me to be a better person in every way.


**BIOGRAPHY**

Byungsoo Kim worked as a designer and a researcher for several years. He earned his bachelor’s degree in Product Design from Hong-ik University and his master’s degree in Industrial Design at North Carolina State University. He is a global design awards winner, including the GM Interactive Design Competition, iF Design Award, Red Dot Design Award, and other national and international awards.

Since 2016, he has been involved in preparing and delivering design thinking short courses and workshops to Laboratory for Analytic Sciences (founded by the National Security Agency) staff and members. He also conducts ergonomics and user experience research. He designed and tested an aging experience suit as a lab project and helped develop a simulator and usability test protocol for Hanes brand at the RED lab. His research work was published as a journal paper, received the HFES Product Design TG Student Paper Award in 2019, and has been presented at several international conferences. His research interests are user experience and usability study of products, design thinking process and methods, and interdisciplinarity in design research.
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CHAPTER 1
INTRODUCTION

Background

There are two main New Product Development (NPD) approaches to achieving innovation — market-driven and technology-driven (Chaudhary, 2005; Ettlie & Subramaniam, 2004; Veryzer Jr., 1998). The market-driven approach is defined as developing a new product based on the value that customers are interested in (Vorhies, Harker, & Rao, 1999). The technology-driven approach is defined as creating something which is dependent on technology (“Technology-driven Definition in the Cambridge English Dictionary,” n.d.). The technology-driven approach drives companies to focus on investing in the research and development of technology to enhance its capabilities in order to better differentiate their products and services from those of competitors (Berman & Hagan, 2006; Gatignon & Xuereb, 2016; Rosenberger & Kathleen, 2015; Zhou, Yim, & Tse, 2005).

The technology development process and technology-driven NPD process are two separate processes (Keersmaecker, Jacoby, & Baelus, 2012). While technology development focuses on creating state-of-the-art technology, technology-driven NPD focuses on developing a new and innovative product. The front end of the technology-driven NPD process includes the transition from technology development to product development. This transition is referred to as “technology transfer” (Keersmaecker et al., 2012). Since the role of design has been expanded through the NPD process, there is potential for design to play a more significant role during the technology transfer phase as well.

A technology-driven firm is a company that has a clear focus on developing technology-related R&D products and uses technology as a source for developing future products (Hao &
Song, 2016). Previous studies have shown that a large percentage of the companies pursuing discontinuous NPD (e.g., the development from a button type cellular phone to a touchscreen smartphone), also known as innovative NPD, tend to take a technology-driven approach (Ali, 1994; Veryzer Jr., 1998). A 2016 report on the value of design illustrates that almost 28% of companies in the UK take a technology-driven approach rather than a market-driven approach. In other words, these companies focus more on “developing technologies and then seeking markets for them” rather than “identifying market needs first and then sourcing the technologies for it” (Cooper, Hernandez, Murphy, & Tether, 2017).

Based on previous studies, it appears to be beneficial for companies to take a technology-driven approach (Hao & Song, 2016). First, technology-driven firms tend to have higher product performance (Braguinsky, Klepper, & Ohyama, 2012; Eesley, Hsu, & Roberts, 2013). Second, the products developed by technology-driven firms compete well with their competitors’ products in the market because their products are technologically superior (Gatignon & Xuereb, 1997; Hurley & Hult, 1998; Song & Parry, 1997). Third, the technology-driven approach enables firms to enter a new market and to deliver products to market rapidly because it skips the lengthy period of traditional market research (Mu & Di Benedetto, 2011). Finally, discontinuous innovation is strongly associated with technological advances (Ali, 1994; Maarse & Bogers, 2012; Tushman, 1997). This may be because in order to develop products in this way, “managers find specific uses or markets for a promising new technology” (Ali, 1994).

As there has been an increasing number of multidisciplinary, interdisciplinary, and transdisciplinary projects and research studies within universities in recent years, Design departments have begun collaborating with other departments, including Electronic Engineering, Computer Science, and Industrial Engineering, to develop new products. Nowadays, Industrial
Design (ID) students have increased opportunities to interact with Engineering departments to develop new product ideas. Most ID education programs offer numerous opportunities for students to learn the market and user-centered approaches; however, the discipline seems to lack curriculum on the technology-driven approach. For this reason, while ID students are typically familiar with NPD projects initiated by users’ needs, many students lack confidence when collaborating with those outside their field on technology-driven NPD projects.

Teaching the design process using a technology-driven approach and letting students have technology-driven design experiences may help students learn how to obtain critical technological knowledge and confidence so that they can transform their understanding of technologies into product ideas. Since some design students have a fear of new technologies, experiencing a technology-driven NPD approach within their curriculum could lower the barrier to learning about new technologies. This may enhance their confidence in interacting with technologists and engineers and improve design students’ communication skills in an interdisciplinary team environment. The contemporary industry is moving toward the 4th Industrial Revolution, which includes the emergence of breakthrough technologies, such as artificial intelligence (AI), the Internet of Things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing (Schwab, 2016). Having technology literacy will benefit ID students by allowing them to integrate these cutting-edge technologies into the products they design.

Based on the previous studies, a proposition regarding how to improve the contribution of design education to the contemporary industry has been developed by the researcher of this dissertation study. More effective education for design students, at least at university level, including 1) understanding advanced technology and applying knowledge of technology to
everyday life and 2) having a technology-driven approach to the academic experience, would improve the contribution of design education to the industry. While there are a number of methods and tools taught in design education to support market- and design-driven NPD, there have been a relatively smaller number of documented studies regarding the design methods and tools that support the process of technology-driven NPD (B. Kim & Joines, 2019). Also, there are few studies documenting the teaching of the design process using a technology-driven approach in ID education.

**Ontology and Theoretical Perspective**

Ontology is the first step to understanding a researcher’s approach to knowledge and the perception of reality. People look at the world and consume information differently depending on how they define “knowledge” and “reality.” Understanding the theoretical perspectives prior to consuming research papers aids understanding of the research design strategies and logic (Crotty, 1998). Understanding the theoretical perspective of a certain research study is important because the theoretical perspective implies not only ontology (the worldview of the researcher who conducted the study regarding “how things really are” (Crotty, 1998)) and epistemology (the relationship of the researcher to “that being researched” (Groat & Wang, 2013)), but also the methodology (research strategies to identify the methods to be used in a study (Ishak & Alias, 2005)) of the research.

Post positivists and constructivists have different ontological and theoretical perspectives on “knowledge.” Philip Plowright, Professor at Lawrence Technological University, mentioned his ontological approach during a lecture at North Carolina State University in 2018 (Plowright, 2018). Plowright started his lecture by showing the audience a picture of a mountain and asking
them, “What is the definition of ‘mountain’?” According to Plowright, the definition of “mountain,” or the description of an object (Hacking, 1999), is constructed by people. The definition of “mountain” in the Oxford English Dictionary is “a natural elevation of the earth surface rising more or less abruptly from the surrounding level and attaining an altitude which, relatively to the adjacent elevation, is impressive or notable” (“Definition of mountain,” n.d.). As “impressive” and “notable” are subjective terms, it is difficult to have a universal definition of the word “mountain.” How it is defined depends on what people agree to call certain peaks in the ground based on how they define “impressive” and “notable.” In this context, knowledge of the definition of “mountain” is constructed by socio-cultural context. This is a constructivist’s ontology and perspective (Groat & Wang, 2013).

However, the example of the definition of “mountain” could also be explained by a researcher who has a different ontology and perspective. For instance, the peak called a mountain itself can be considered an always-existing reality, separate from researchers, and the attempt to define and to understand the mountain is an effort to find objective knowledge about the meaning of the word “mountain.” It is possible to choose one peak which is called a mountain, measure the height and the degree of it, and document the information. In this way, all of the peaks called mountains in the world can be measured, and knowledge about the different heights and degrees of mountains can be obtained. This approach is a post positivist’s point of view rather than a constructivist’s one, because post positivists believes that there is an objective reality and that researchers are trying to find objective knowledge (Guda & Lincoln, 1998).

Clearly, even if researchers work on the same topic, different ontologies and theoretical perspectives create different approaches to their research. Another example of having a different approach to the same subject would be studying yeast. Yeast itself exists apart from human
beings. Chemists can explore the micro level components and the function of yeast, which is a post positivist’s approach. In contrast, the knowledge of how to use yeast to bake different kinds of bread can be studied by a baker. From the baker’s point of view, cultural preferences regarding the taste of various types of breads made in different countries and regions are important variables. This is a similar ontology to that of a constructivist: knowledge (in this case, different ways of using yeast for baking different types of breads) can be varied. A chemist’s fundamental and objective knowledge of yeast (apart from human activity) is applied in baking (human activity), and various baking knowledge is socially constructed by bakers in different cultures and regions over time.

The first category of knowledge is different from the second category. Understanding knowledge objectively, apart from human activity, is a post positivist’s point of view. This form of knowledge (the objective knowledge of tangible or intangible “being” apart from human activity, such as that of yeast) will be referred to as “objective knowledge” in this paper. Understanding how knowledge is being used by humans in a social context, on the other hand, is a constructivist’s point of view. This form of knowledge (e.g., the knowledge of baking breads using yeast) will be referred to as “constructed knowledge” in this paper. If a researcher focuses on understanding objective knowledge, the researcher’s approach tends to be post positivist. If another researcher is interested in understanding constructed knowledge, the researcher’s theoretical perspective would then be closer to constructivism.

According to Oxford Dictionaries, the definition of “reality” is “the state of things as they actually exist, as opposed to an idealistic or notional idea of them” (“Definition of reality in English by Oxford Dictionaries,” n.d.). In fact, “reality” can be defined in two different ways. First, there is the reality that exists which is not constructed by humans. For instance, air, yeast,
and other organisms existing in the world perhaps even before mankind fall into this type of reality. Post positivists focus on obtaining objective knowledge about this reality. Secondly, there is the reality constructed by humans, such as air conditioners, bread, and other artificial objects created by humans. The second type of reality will be referred to as “constructed reality” in this dissertation study. Constructivists focus on understanding knowledge about this constructed reality.

The author defines two types of constructed knowledge and constructed reality in this dissertation study. The first type is “constructed core knowledge” and “constructed core reality”; the second type is “constructed variable knowledge” and “constructed variable reality.”

Constructed core knowledge and constructed core reality will be defined in this paper as the knowledge and the reality that are socially constructed and have been used for a long period of time (i.e., for more than a few decades). For instance, there are terms of constructed reality that have been used in a consistent way for centuries, since they were first created, such as “mountain” and “water.” The usage and meaning of those terms have never changed. On the other hand, there are certain terms with meanings that are socially constructed at a certain period of time, which disappear over time, such as slang. The knowledge and the reality are socially constructed and are being used by a large group of people, but they disappear or their meaning changes over a relatively short period of time compared to constructed core reality. This will be defined as constructed variable knowledge and constructed variable reality in this paper. The definitions of post positivism and constructivism along with the terms defined in this study are visualized in Figure 1. Different visualizations indicate different meanings, as shown at the bottom of Figure 1. The visualizations will be used for most of the conceptual visualizations in this study.
The author’s ontological and epistemological stance on the industry is constructivism. The industry is constructed reality, and constructed knowledge influences and changes the industry over time. For instance, the industry changes as constructed knowledge emerges and disappears, such as emerging advanced technologies, customers’ perception of value, and social trends (Bardhi & Eckhardt, 2012; Chen, 2009; “IBM Head of Design, Phil Gilbert, wields $100M and 1,300 designers to bring design back to IBM - YouTube,” 2017). It is vital for companies in the industry to understand these changes and to simultaneously adapt the changes into their organization for success (Pedler & Aspinwall, 1999).

Phil Gilbert, the General Manager of Design at IBM Corporation, mentioned the influence of advanced technology in the industry during an interview in 2017 (“IBM Head of Design, Phil Gilbert, wields $100M and 1,300 designers to bring design back to IBM - YouTube,” 2017). There are many advanced technologies emerging rapidly, such as IoT, VR, and AR, and these have influenced the quality of the products and services developed by companies.
Customer perception regarding the value of products (constructed variable knowledge) also changes over time. For instance, an especially large portion of the younger generation has shifted their perception of owning objects toward having temporary access to products and services when needed. Those customers now prefer to pay for short-term use of a product to fulfill their needs instead of owning products permanently (Bardhi & Eckhardt, 2012). Under this social trend, “We are moving toward an economy where physical assets are shared as services” (Yaraghi & Ravi, 2017, p. 6) and it influences the products and services developed by companies in the industry.

The author’s ontological and epistemological stance on the role of design and design education is constructivism. Design has taken on the role of increasing the value of products for users and products, and the contribution of design is crucial for the companies that focus on developing and selling new products and services to customers (Cooper et al., 2017; Heskett, 2001). As the industry’s constructed reality changes over time, the role of design in the industry needs to be shifted accordingly. If designers are well prepared through design education to adapt to their new role, they can maximize their contribution to the industry. For instance, in the early 20th century, to meet the growth of the capitalist industry, the design industry needed to develop products whose shape was both manufacturable and aesthetically pleasing (Heskett, 2001). To respond to these needs of the industry, designers were mainly only involved in developing decorative forms in an easily manufacturable way at that period of time (Heskett, 2001). Compared to the past, nowadays, as the importance of the design process has been recognized, designers are not only involved in the appearance design but are expanding their role across the whole product development phase (Cooper et al., 2017).
Design education is responsible for teaching students to develop their design-related skills and knowledge so that they can work confidently as problem-solvers in the industry (Goldschmidt & Casakin, 1999). Hence, design education should respond to their changed role in the industry and should update its educational content to echo the changed industry so that design students can be ready to maximize their contribution as designers to the industry. If the role of design is changed from A to A’ or B, design education also needs to be updated from A to A’ or B.

**Conceptual Framework**

A conceptual framework is helpful to develop the process of theorization (Jabareen, 2009). A conceptual framework that explains the relationship of industry, the role of design and designers, and design education is visualized in Figure 2.

*Figure 2.* Author’s epistemological stance on the industry, the role of design(ers) in the industry, and design education.
CHAPTER 2

LITERATURE REVIEW

More literature related to the conceptual framework was reviewed and is documented in the following sections. The literature review was conducted to better understand constructed knowledge and constructed reality regarding industry.

New Product Development Process

Companies in industry develop hardware and software products to attain profit. The New Product Development (NPD) process consists of sequential stages, including: 1) opportunity identification, 2) concept and idea generation, 3) product design and engineering, 4) prototype testing and development, and 5) commercial production and launching the final product (Carson, Wu, & Moore, 2012; Luo, 2015) (see Figure 3).

![Figure 3. Product development model (image retrieved from Carson et al. (2012)).](image)

Different NPD Approaches

There are three main approaches in NPD: 1) market-driven, 2) design-driven, and 3) technology-driven (Chaudhary, 2005; Ettlie & Subramaniam, 2004; Veryzer Jr., 1998). The market-driven approach is defined as developing a new product based on the value that
customers are interested in (Vorhies et al., 1999). The well-known definition of design-driven from Verganti, known as the design-driven innovation approach, is enhancing the role of designers in the NPD process to achieve innovation (Chaudhary, 2005). The design-driven approach is newer for companies compared to the technology- and market-driven approaches (Lievesley et al., 2018). The technology-driven approach is defined as NPD that is dependent on technology (“Technology-driven Definition in the Cambridge English Dictionary,” n.d.). The technology-driven approach drives companies to focus on investing in technology research and development (R&D) to enhance their capabilities in terms of differentiating their products and services from those of their competitors (Berman & Hagan, 2006; Gatignon & Xuereb, 2016; Rosenberger & Kathleen, 2015; Zhou et al., 2005). The market- and technology-driven approaches have traditionally been the dominant NPD approaches (Ettlie & Subramaniam, 2004). A 2017 report entitled “Design Value: The Role of Design in Innovation” illustrates that companies follow different approaches along the spectrum from technology-driven to market-driven (Cooper et al., 2017) (see Figure 4).

![Figure 4](image Retrieved from Cooper et al. (2017)).

**Figure 4.** Technology or market led approaches (image retrieved from Cooper et al. (2017)).

**Innovation in Industry**

**Approach 1** (Innovation Classified by Technological Breakthrough): Many scholars have observed that innovation is crucial for company success (Ali, 1994; Corso & Pellegrini,
2007; Norman & Verganti, 2013; Walsh, 1996). While different scholars identify innovation differently, such as “radical, incremental, really new, discontinuous, imitative, architectural, modular, improving, and evolutionary innovations” (Garcia, 2002, p. 110), many scholars categorize innovation into different types in terms of the level of technological breakthrough and newness (Ali, 1994; Robertson, 1971; Tushman, 1997; E. Yoon, 1985).

Ali and Robertson define discontinuous and continuous innovation based on whether the innovation is from a technological breakthrough or existing technologies (Ali, 1994; Maarse & Bogers, 2012). They define pioneering (discontinuous) products as follows:

*The idea of product development in this article is similar to what Robertson called radical or discontinuous versus incremental or continuous innovation. We define pioneering products as technological breakthroughs. Managers design such products to find specific uses or markets for a promising new technology.* (Ali, 1994)

Based on their definition, discontinuous products are developed by finding uses or markets for new and promising technology. Incremental products are defined as minor extensions and modifications of existing products to meet unsatisfied customers’ needs using existing technologies (Ali, 1994; Maarse & Bogers, 2012). An example of discontinuous products versus incremental products would be to develop the first car from riding a horse versus improving the current version of the horse saddle to be more comfortable than the one on the market.

Tushman defines incremental, architectural, and radical innovation based on the technology cycle (Tushman, 1997). Based on Tushman, discontinuous innovation starts from technological discontinuity. In the period of technological discontinuity (see Figure 5), numerous
innovative products are developed with the application of advanced technologies to seek new possibilities. This period is called the variation phase. After the variation period, the industry standard is set, and architectural and incremental innovation come into play in the selection and retention phase.

![Technology cycle](image)

Figure 5. Technology cycle (image retrieved from Tushman (1997)).

**Approach 2 (Innovation Classified by Novelty and Consumer Behavior):** Yoon categorizes innovation into two types, discontinuous and continuous innovation, based on the level of originality. For instance, Yoon explains discontinuous innovation as “original new products” while incremental products are defined as “reformulated new products” (E. Yoon, 1985).

In 2018, Hoyer and MacInnis explained innovation based on customer behavior. They
define innovation as new products and services that 1) offer something new to customers and 2) can bring some changes in “acquisition,” “consumption,” and “disposition patterns” (Hoyer & MacInnis, 2018). Based on Hoyer and MacInnis, a product is innovative if customers perceive it as new and as having unique features that benefit the consumer, whether or not they are actually new in the world. For instance, if customers perceive a product as not a new one and without any features that benefit them, the product is considered a failed innovation no matter how much money and effort were spent on its development (Hoyer & MacInnis, 2018). On the other hand, if a product is innovative and provides new benefits to customers in a particular region or nation, the product is innovative in that region or nation even if it is already in common usage in another region or nation:

…U.S. and European consumers may consider something to be new that has been available to consumers in developing countries sometimes. For example, consumers in Africa and India had the ability to complete cash transactions via cellphones years before such payment services became commonplace in U.S. markets. (Hoyer & MacInnis, 2018, p. 406)

Also, while Hoyer and MacInnis agree that innovativeness ranges from continuous to discontinuous, they define different types of innovation in terms of the creation of consumption patterns (2018). The types are as follows: 1) discontinuous innovations (something distinctly new that completely changes the consumer’s behavior); 2) dynamically continuous innovations (“pronounced effect on changing the consumption pattern,” such as the invention of the laptop or tablet); and 3) continuous innovations (“minor effect on changing the consumption pattern,” such as a tablet with an e-book reader, in-cloud data storage, or digital video cameras) (Hoyer & MacInnis, 2018). These examples of discontinuous, dynamically continuous, and continuous
innovation have been visualized by Hoyer and MacInnis and are shown in Figure 6.

![Figure 6. The innovation continuum (image retrieved from Hoyer & MacInnis (2018)).](image)

**Approach 1 and Technology- and Market-Driven NPD:** Based on many scholars who categorize innovation into the Approach 1 mindset, discontinuous products are strongly associated with technological advances (Ali, 1994; Maarse & Bogers, 2012; Tushman, 1997). Ali specifically mentions that in order to develop such discontinuous products, “managers find specific uses or markets for a promising new technology” (Ali, 1994, p. 55). This premise aligns with the definition of technology-driven innovation, or innovation which is dependent on technology (“Technology-driven Definition in the Cambridge English Dictionary,” n.d.).

In the 1950s, because of the many technological breakthroughs of the decade, the technology-driven approach to innovative product development was prevalent during a period of rapid industrial expansion (Maarse & Bogers, 2012). Schwab notes that the current industry is moving toward the 4th Industrial Revolution, which includes the emergence of breakthrough technologies, such as artificial intelligence (AI), the Internet of Things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing (Klaus, 2016). Based on the technology cycle (Figure 5), the current industry is considered to be in the phase of “technological discontinuity.” The current industry is
expanding with the application of advanced technologies, such as the rapid growth of the app and web industry because of AI and deep learning. As the technology-driven approach was a major driver of discontinuous innovation during the period of rapid industrial expansion in the 1950s, technology-driven innovation is expected to play an important role in finding new opportunities in the current market as well. For instance, as virtual reality (VR) and augmented reality (AR) technology have been applied in the gaming industry, numerous new and innovative products, both tangible (e.g., a variety of VR headsets) and intangible (e.g., different VR and AR games and apps), have been developed to find new opportunities in the gaming market.

Scholars have observed that market-driven innovation, developing a new product based on the value that customers are interested in (Vorhies et al., 1999), helps companies to achieve incremental innovation by meeting customers’ demands using existing technology (Ali, 1994; Maarse & Bogers, 2012). The market-driven approach is a main driver of growth in a mature market (Ali, 1994; Maarse & Bogers, 2012). For instance, during the 2nd (1870s) and 3rd (1960s) Industrial Revolutions, as companies utilized the same manufacturing and technological processes, constant changes in product appearance and function based on customers’ needs were necessary to stimulate the market (Heskett, 2001).

In summary, based on Approach 1, the technology-driven approach is strongly associated with discontinuous innovation while the market-driven approach is associated with continuous or incremental innovation. It is important for companies to pursue market-driven innovation to develop continuous products in addition to technology-driven innovation to develop discontinuous products for short- and long-term success (Tushman, 1997).

**Approach 2 and Technology-Driven NPD**: As mentioned above, Approach 2 focuses on innovation based on customer behavior. In the modern world, products with advanced
technology in a certain domain may have a positive impact on the success of a company by changing customer behavior. For instance, Pokémon Go, an innovative gaming app released in 2016, completely changed player behavior compared to previous versions of Pokémon games. Pokémon Go players must interact with the outside world and build networks with other people to succeed in the game. It requires a different behavior than previous versions of Pokémon games, which are often played at the user’s home and alone. While there has been no documented confirmation that Pokémon Go was developed from a technology-driven approach, the key feature of the app is AR technology, which changed the entire context and format of the game; thus, it seems advanced technology (in this case, AR) was a main driver in developing Pokémon Go. In this example, technology-driven innovation led to discontinuous innovation.

However, there are also some products that started from technology and did not change consumer behavior. For instance, while curved display technology changed the form of TV displays, the technology did not change the way customers interact with TVs. Therefore, the technology-driven approach does not necessarily always result in discontinuous products. Pokémon Go opened up a new gaming market because it suggested a new meaning of gaming to customers that satisfied customers’ hidden desires, such as interacting with virtual monsters in their real-life environment. This provides new value and gives new meaning to the players. On the other hand, a curved display TV seems to be simply applying advanced technology to an existing product without much consideration of providing distinctive new value and meaning to customers. Based on Approach 2, while there are certain benefits of applying a curved display to a TV, a curved display TV is a continuous product (not even a dynamically continuous product).

According to the definition of discontinuous innovation from Hoyer and MacInnis (Approach 2), creating and improving the value of and giving new meaning to products that
change customer behavior are necessary criteria to meet in addition to the application of advanced technologies. Since the core of design discipline is creating and increasing the value of products (Cooper et al., 2017; Heskett, 2001), designers are expected to contribute to developing products that are unique and provide new and valuable meaning to customers. In technology-driven NPD, similar to the curved display TV, a technology-driven approach sometimes meets the criteria for continuous innovation. Designers can use their creativity to envision products from technology that create new and meaningful value with a technology-driven approach.

Since radical and innovative products play an important role in driving the growth of a company (Ali, 1994; Calantone & Benedetto, 1988; Kleinschmidt & Cooper, 1991), the discontinuous NPD process for innovation has received more attention in practice. A discontinuous NPD model is shown below (see Figure 7).

![Figure 7. Discontinuous New Product Development Process Model (adapted from Veryzer Jr. (1998)).](image)

**Technology-Driven Organization**

A technology-driven firm is a company that has a clear focus on developing technology-related R&D products and uses technology as a source of developing future products (Hao & Song, 2016). Based on the literature, there are several benefits for companies that take a technology-driven approach (Hao & Song, 2016). First, technology-driven firms tend to have higher product performance (Braguinsky et al., 2012; Eesley et al., 2013). Second, the products
developed by technology-driven firms compete well with competitors’ products in the market because their products are technologically superior (Gatignon & Xuereb, 1997; Hurley & Hult, 1998; Song & Parry, 1997). Third, the technology-driven approach enables firms to enter new markets and to deliver products to market rapidly because it skips the lengthy period of traditional market research (Mu & Di Benedetto, 2011).

Based on previous studies, a large percentage of companies pursuing discontinuous NPD tend to take a technology-driven approach (Ali, 1994; Veryzer Jr., 1998). Discontinuous NPD (e.g., the development from a button type cellular phone to a touchscreen smart phone), also known as innovative NPD, focuses on developing a product from emerging technologies (Veryzer Jr., 1998). The constructed core knowledge and constructed core reality of industry based on the current literature are summarized and visualized in Figure 8.
Changes in Industry

There have been three disruptive industrial revolutions in the past. During the 1\textsuperscript{st} Industrial Revolution at the end of the 18\textsuperscript{th} century, “the emergence of mechanization” enabled the agricultural industry to become the main economic driver (“Industrial revolutions: The 4 main revolutions in the industrial world,” n.d.). About a century later, due to the emergence of technology using new sources of energy, the gas, fuel, and chemical-related industry became a main driver (the 2\textsuperscript{nd} Industrial Revolution) (“Industrial revolutions: The 4 main revolutions in the industrial world,” n.d.). During this period of time, large factories and mass production became mainstream, and over the next hundred years, these developments, along with the improvement
of electrical energy usage, enabled mass production and automation of manufacturing (Heskett, 2001; “Industrial revolutions: The 4 main revolutions in the industrial world,” n.d.). For this reason, manufacturability for mass production, cost efficiency, and functionality were important factors to consider regarding manufactured products during this period (Heskett, 2001). During the 3rd Industrial Revolution in the second half of the 20th century, industries focused on producing tangible and intangible products via automated production (Schwab, 2016). The 3rd Industrial Revolution can be characterized by “a fusion of technologies that [blurs] the lines between the physical, digital, and biological spheres” (Schwab, 2016, p. 2).

Many studies show that the current state of industry is moving toward a 4th Industrial Revolution due to advanced technology, such as information technology (IT), cloud-based data storage, machine learning, and deep learning (“IBM Head of Design, Phil Gilbert, wields $100M and 1,300 designers to bring design back to IBM - YouTube,” 2017; “Industrial revolutions: The 4 main revolutions in the industrial world,” n.d.). This technology enables the current industry to provide intangible products, such as apps and networking services, that improve quality of life for consumers. In addition to these intangible products, as a result of the rise of 3D printing technology, the medical and health care industry are now capable of providing customized products and services to their patients and clients (Petrick & Simpson, 2013).

The emerging challenges nowadays are complex and difficult for one discipline alone to solve (“IBM Head of Design, Phil Gilbert, wields $100M and 1,300 designers to bring design back to IBM - YouTube,” 2017). Hence, interdisciplinary effort has become an important element for companies in order to achieve innovation (Barry, Born, & Weszkalnys, 2008).

Based on the literature review regarding how industry has changed over time, the constructed variable knowledge and constructed variable reality of industry are summarized and
visualized in Figure 9.

![Diagram](image)

*Figure 9. Changes in the industry.*

**Understanding the Role of Design in Industry**

The literature was reviewed to examine constructed knowledge and constructed reality regarding the role of design in industry.

While the role of design in industry changes over time, its core role has been defined in the previous section: increasing the value of products for users and clients (Heskett, 2001; Cooper et al., 2016). Constructed core knowledge and constructed core reality regarding the role of design and designers in industry are visualized accordingly in Figure 10.
As briefly mentioned in the previous section, the industry in the early 20th century needed products that were manufacturable and aesthetically pleasing (Heskett, 2001). To respond to this need, artists acted as designers and were involved in decorative forms of development (Heskett, 2001). During the same period of time, the role of designers in product development was to design products that were functional and usable (Heskett, 2001).

Nowadays, design has taken an important role in NPD to help develop innovative products and increase product value. In the Value Creation Theory model, design helps to generate opportunities for product innovation (Budge, 2012). In the united innovation subprocesses model, design plays an important role in bridging science (technology) and entrepreneurship (Luo, 2015). See Figure 11 for details of these two models.
There are numerous theoretical models that demonstrate how the design process helps in developing user-friendly and innovative products, such as the Double Diamond (“The Design Process: What is the Double Diamond? | Design Council,” n.d.), Spiral Methodology (Boehm, 1988), and User-Centered Design (Glushko, 2008). The common ground found among the theoretical models regarding the design process are as follows: 1) problem identification via user research, 2) brainstorming product ideas to solve the identified problem, 3) prototyping, and 4) presentation of the final solution. The design-driven approach, which focuses on the process of developing products in a meaningful and useful way regarding form, quality, and customer experience, utilizes these commonalities of the design process (André Liem & Sanders, 2011). Based on the literature review, constructed variable knowledge and constructed variable reality regarding the role of design and designers in industry are visualized in Figure 12.
Figure 12. Changed role of design(ers) in industry.

Understanding the Role of Design Education

The literature was reviewed to investigate constructed knowledge and constructed reality regarding the role of design education.

The core role of design and designers in industry is defined, as discussed in the previous section, in the following way: teaching students to develop skills and knowledge so that they can work confidently to solve problems and challenges in the industry (Goldschmidt & Casakin, 1999). In other words, design education should respond to the changed role of the designer in the industry. Since the chief role of design and designers (in other words, the constructed core knowledge about the role of design) is to increase the value of products for users and clients (Heskett, 2001; Cooper et al., 2016), the aim of design education should be to teach students to be the designers who can create/increase the value of products. Constructed core knowledge and constructed core reality regarding design education are visualized in Figure 13.
Historically, in order to meet the industry’s needs, art and craftsmanship were taught to design students so that they could learn artistic creativity and research to design products (Phocas, 2015a). The former German art school Bauhaus, for example, educated its students regarding how to design objects considering the simple aesthetic aspect of the product for mass production (Phocas, 2015a; Schlick, 2009). The “practice informs teaching” model was also initiated by Bauhaus, which trains design students to solve problems through project-based learning (Phocas, 2015a).

Design thinking, also known as user-centered design process, has been recognized as playing a crucial role in achieving innovation in industry (Verganti, 2009b). Therefore, modern design education programs teach students how to conduct primary research, such as through interviews and observation, to find insights from end users and stakeholders in the studio-based model and problem-based design programs (Mubin, Novoa, & Al Mahmud, 2017).

While the collaboration between architecture and art was initiated by Walter Gropius, the founder of Bauhaus in 1919 (Phocas, 2015b), interdisciplinary work across disciplines (including non-design disciplines) was not a common model in design education for many decades. As the

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*Figure 13. The role of design education.*
benefits of interdisciplinarity are recognized in the current industry, however, recent studies have highlighted its importance in design education, including the collaboration of designers with engineering and technology departments (Haritaipan, Saijo, & Mougenot, 2018; Mubin et al., 2017). Many graduate level design programs try to cultivate interdisciplinarity for their students (Harris, Girad, & Pijawka, 2003). For example, Product Innovation Lab at North Carolina State University is a semester-long interdisciplinary class (“Product Innovation Lab: Collaboration Leads to Success | Jenkins MBA | NC State University,” n.d.). Through this program, industrial design students collaborate with MBA and engineering students to work on a problem-based project. However, unsatisfactory results in design doctorate programs associated with implementing interdisciplinarity have been pointed out in some studies (Margolin, 2010).

Based on the literature review, constructed variable knowledge and constructed variable reality regarding design education are visualized in Figure 14.

*Figure 14.* Changes in design education, from the past to current.
Industry, the Role of Design(ers), and Design Education

The results of the literature review imply the interconnectedness of industry, the role of design and designer in industry, and design education in terms of constructed reality and constructed knowledge. In the past, as industry influenced the role of design and designer to contribute to the industry by designing mass producible and aesthetically pleasing products, design education taught art and craftsmanship and focused on how to design functional and mass producible goods so that designers could maximize their contribution to the industry. Currently, because of rapid technological innovation and the importance of interdisciplinarity for innovation and entrepreneurship, the role of design and designer is to bridge the gap between technology and entrepreneurship and to connect technological ideas and users’ needs (Luo, 2015; (Budge, 2012). The current design education model instructs students by teaching design thinking and asking students to form interdisciplinary teams with students from other departments, including engineers, along with cultivating interdisciplinarity at the graduate student level.

The summarized results of the reviewed literature are visualized along with conceptual mapping, the author’s epistemological stance on design education, the role of design and designer in industry, and design education (Figure 2) to understand the relationship among them (influence and contribution to others) (see Figure 15).
Systematic Literature Review: Design Methods and Tools to Support Technology-Driven Approach

A systematic literature review (Gough, Oliver, & Thomas, 2017) was conducted to answer the following questions: 1) what is the role of design in technology driven NPD? and 2)
what are the existing the design methods and tools used at the front end of technology-driven NPD process?

The systematic literature review is formatted as a manuscript for the submission in category to a conference proceeding and was presented at 10th International Conference on Applied Human Factors and Ergonomics in July, 2019.

Title: The Role of Design in Technology Driven Ergonomics Product Development

Authors: Byungsoo Kim and Sharon Joines (College of Design, North Carolina State University, Raleigh, NC)

Abstract: Human Factors and Ergonomics (HFE) have been considered in New Product Development (NPD) to develop solutions that are useable and useful while maintaining productivity. The importance of technology and design has increased at the intersection between NPD and HFE. Developing a new product driven by technology is known as a technology driven approach which can be infused into existing ergonomic product development processes and may result in the development of effective, new and innovative products. The purpose of this study is to instigate design methods and tools that can be applicable to the technology driven NPD process. The literature regarding existing design methods and tools used and potentially utilized in technology driven NPD process has been reviewed in this study. Also, the role of HFE experts in a technology driven NPD process is addressed in the discussion section. In addition, when to use the design methods and tools found in the literature in the front end of the technology driven NPD process is suggested in this paper to help develop new and innovative products.
Methods:

To find the literature that is relative, recent, and valid, the inclusion criteria was set prior to conducting the search (see Table 1).

Table 1. *Criteria for literature inclusion.*

<table>
<thead>
<tr>
<th>Type</th>
<th>Inclusion criteria</th>
</tr>
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<tbody>
<tr>
<td>Topic</td>
<td>Literature must relate directly to one of the research questions.</td>
</tr>
<tr>
<td>Recency</td>
<td>Literature should be published between 1998 to 2019.</td>
</tr>
<tr>
<td>Study target</td>
<td>Literature should relate to higher educational settings (university students) or in practice (professional designers and other experts (e.g. engineers) involved in technology driven NPD process).</td>
</tr>
<tr>
<td>Research base</td>
<td>Literature must be based on:</td>
</tr>
<tr>
<td></td>
<td>Empirical research (findings based on actual experience, either qualitative or quantitative) about the existing methods and tools or Suggestions of methods and tools including: Case study Theoretical research Literature review</td>
</tr>
<tr>
<td>Transparency</td>
<td>The study methodology should be well defined (e.g. procedure, sample sizes, instruments, and analysis).</td>
</tr>
<tr>
<td>Reliability/validity</td>
<td>The findings from the literature must be valid and reliable (e.g. the finding and conclusion should be based on the results of the study, cases, and/or other related literature)</td>
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</table>

Initially online databases were used to find relevant literature in key journals related to design, technology, and education. A second phase of the literature review consisted of the reviewal of the initial articles’ references, searches on the authors of the initial articles, and informal internet searching by topic. The second phase revealed additional related journal
articles, conference proceedings and book chapters. The types of literature and sources searched
are summarized in Table 2. Search terms are presented in Table 3.

Table 2. *Types of literature and sources searched.*

<table>
<thead>
<tr>
<th>Type of literature</th>
<th>Source searched</th>
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<tbody>
<tr>
<td>Key journal articles</td>
<td>Online databases:</td>
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<tr>
<td></td>
<td>Web of Science, Science Direct</td>
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<tr>
<td></td>
<td>Scanning the contents of key journals:</td>
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<tr>
<td></td>
<td>Ergonomics, Design studies, International Journal of</td>
</tr>
<tr>
<td></td>
<td>Technology and Design Education, Design and</td>
</tr>
<tr>
<td></td>
<td>Technology Education, International Journal of</td>
</tr>
<tr>
<td></td>
<td>Design, Thinking Skills and Creativity</td>
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<tr>
<td>Additional journal articles,</td>
<td>Google Scholar</td>
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<td>conference proceedings, and</td>
<td>Google</td>
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<tr>
<td>book chapters</td>
<td>Researchgate</td>
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Table 3. *Search terms.*

<table>
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<th>Terms</th>
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<tbody>
<tr>
<td>Included technology driven new product development design; technology forces; technology centric; technology transfer; technology; technology adoption; design process; user centered design; customer experience; tools; methods; higher education; capstone; creativity; innovation skills; innovation; product innovation; breakthrough innovation; radical innovations; front-end innovation; technology integration; inspiration tool; project based curriculum; brainstorming; fuzzy front end; engineering; engineers; new product development; capstone; innovation skills</td>
</tr>
</tbody>
</table>
Findings:

Approximately a thousand journal articles between 1998-2019 were found using the aforementioned search terms. After reviewing the ~1000 journal papers based on the inclusion criteria (described in Table 1), only 25 journal articles were found to be related to the research questions. The second phase of the literature review produced 2 conference proceedings, and 2 book chapters. The relevant literature included 22 empirical studies, 6 literature reviews and a case study for developing framework, methods, and tools. The empirical studies documented several different research methods including: 1) testing the existing methods and tools using surveys and interviews of students during and/or after coursework or workshops, 2) observing the methods and tools being utilized over a long period of time in companies, 3) interviews with domain experts, such as experienced designers and engineers. The literature review (including case studies) covered previous studies or cases which emphasized the role of design and design methods and tools in technology driven NPD. From the literature review, conceptual frameworks were developed. Also, the methods and tools that are to aid or possibly to be utilized to aid technology driven NPD were identified.

The 29 studies were categorized into the following themes: 1) the role of design in technology driven new product development and innovation, 2) the methods and tools to support user involvement at the front end of technology driven new product development, and 3) the methods and tools for innovative idea generation from technology.

*The Role of Design in Technology Driven NPD and Innovation:* Design helps companies
differentiates their products from competitors’ products by improving performance and attractiveness during product development (Candi, 2007).

Technological advances and design have been key enablers for electronic product development (Blanco, Casas, Manchado-Pérez, Asensio, & López-Pérez, 2017). Recent technology based service projects, including tangible artifacts, have an emphasis on design (Candi, 2007). The designer’s role in a technology driven NPD process is to design product features and systems to enhance the user experience of a product, to facilitate discussions regarding how to rapidly generate ideas for solutions, and to develop the form of the products considering aesthetics and ergonomics (Eder, 2013; Miller & Summers, 2013; Pahl, Beitz, Feldhusen, & Grote, 2007; Ulrich & Eppinger, 2004). Industrial designers interact with engineers to implement the developed design concept into feasible products (Persson & Warell, 2003).

Design has supported product innovation in recent years (Malmberg & Holmlid, 2014). Design has aided new technology development (Malmberg & Holmlid, 2014) and product development (van Schie et al., 2009) to achieve product innovation (Kleinsmann Maaike, Valkenburg Rianne, & Sluijs Janneke, 2017; Verganti, 2009a). Open innovation, sharing information in a creative environment with user involvement, has been receiving attention in industry (Eroğlu & Ekmekcioğlu, 2018). Designers, with a human centered design emphasis, are well suited to the open innovation approach because of their focus on understanding users/customers’ needs; the connection between customers and the design process has been highlighted in the study of innovation (Eroğlu & Ekmekcioğlu, 2018).

Methods & Tools Supporting User Involvement in Tech. Driven NPD: Customer involvement in NPD process has been a helpful approach to obtain information from users (François, Osiurak, Fort, Crave, & Navarro, 2017; Galway et al., 2013; van Schie et al., 2009; B.
S. Yoon & Jetter, 2015). Inadequate understanding of customer needs results in the misperception of “engineers’ wishes” as “customers’ needs” when applying technology into the product development; this has been revealed as a major factor in the failure of innovations (van der Panne, van Beers, & Kleinknecht, 2003). The strong engagement of customers in the early stages of NPD has been emphasized in order to capture the customers’ knowledge and to understand user needs (van Schie et al., 2009).

A global company, Philips’ approach to NPD emphasizes user involvement across three different aspects of product development including Technology Objectives (TO), Design Objectives (DO) and Strategic Marketing Objectives (SO) (Gardien & Kyffin, 2009). Philips developed their TO: DO: SO approach which includes design tools, such as personas, Experience Targets and Slice of Life Experience Prototypes (Gardien & Kyffin, 2009).

While there were no studies in the found journals articles regarding design methods and tools to involve customers at the front end of technology driven NPD, there are methods and tools that enable customer involvement in the early phase of NPD. User-centered design methods and tools help develop end-user centered products which have high customer value (De Jong, Vink, & De Kroon, 2003; Galway et al., 2013; Gardien & Kyffin, 2009; B. S. Yoon & Jetter, 2015). Focus groups (Galway et al., 2013; van Schie et al., 2009), interviews (Albayrak, Wauben, & Goossens, 2009; van Schie et al., 2009; Xu, 2014), cognitive walkthroughs (Galway et al., 2013; van Schie et al., 2009), think-aloud protocols (Galway et al., 2013; van Schie et al., 2009), and observation (Albayrak et al., 2009; Galway et al., 2013; A Liem & Sanders, 2013) have been used to understand the customers’ needs. Since companies prefer less-time-consuming approaches during the early stage of NPD (Casner, Houssin, Renaud, & Knittel, 2015), focusing on interacting with open-minded users, lead users who represent the target group, and/or care
givers (instead of the elderly) allow for effective, efficient understanding of the customers’ needs (Galway et al., 2013; van Schie et al., 2009). Web-based visual customer communication (B. S. Yoon & Jetter, 2015) and co-creation (customer involvement in NPD) (B. S. Yoon & Jetter, 2015) methods have been utilized to connect designers, engineers, and marketers to customer knowledge. The use of user personas (Haag & Marsden, 2018) during user/developer workshops (Albayrak et al., 2009) have been noted to aid empathy in design education (Galway et al., 2013). Attribute listing and storyboarding have supported user involvement during brainstorming (van Schie et al., 2009). User-feedback (Gardien & Kyffin, 2009), focus group sessions (van Schie et al., 2009), express processing (receiving frequent feedback from customers) (B. S. Yoon & Jetter, 2015), storytelling (A Liem & Sanders, 2013), and constructive interaction (interaction between two people with the product and capturing the communication between them) (van Schie et al., 2009) have been suggested to optimize and to improve a second round of ideas from a set of initially generated ideas which involves the users.

Methods & Tools for Innovative Idea Generation from Technology: To aid technology transfer in the early phase of NPD, there are methods and tools to generate innovative ideas inspired by technology. Considering technology as a design material helps designers to focus on generating conceptual ideas (Nordby, 2010). The knowledge from patent analysis for design inspiration was investigated (Ji, Qiu, Feng, & Wu, 2018). Use of “target verb extraction” and “related verb mining” from related product patents to inspire innovative ideas had positive effects for university students for idea generation (Ji et al., 2018). Tangible tools, such as card format, to focus on the potential of touch-points in innovation has been addressed in a previous study (Clatworthy, 2011). One recent study developed cards as inspiration tools for innovative ideas that provide a “magic effect” to encapsulate technical information for novice designers.
While relatively small number of studies were found which explicitly described methods and tools aiding the technology driven NPD process, there were many studies using well-established methods which are potentially applicable for innovative idea generation in the context of technology driven NPD. Different brainstorming methods have been widely used in the creative idea generation phase (Galway et al., 2013; Malmberg & Holmlid, 2014). The goal of brainstorming is to generate as many ideas as possible (Wilson, 2013). Three different types of brainstorming have been used in idea generation: 1) traditional brainstorming (engagement in dialogue and idea sharing), 2) nominal brainstorming (idea generation individually without communicating with others), and 3) electronic brainstorming (use of online resources to facilitate idea generation) (Al-Samarraie & Hurmuzan, 2018). Mind maps, analogies, and round table discussions have been effectively used for in person (classroom) discussions for idea generation (Chua, Yang, & Leo, 2014). C-Sketch (adding ideas to the ideas generated by others in round table format) (White, Wood, & Jensen, 2012), Principles from Historical Innovators (capturing the principles of previously designed innovative products and apply these principles to the concept generation process) (White et al., 2012), and analogy (Goel & Bhatta, 2004) have been utilized for idea generation methods with design students (Haritaipan et al., 2018). Design Heuristics, a tool to help generate more ideas, was suggested to be used after exhausting the initial idea generation phase (Gray, McKilligan, Daly, Seifert, & Gonzalez, 2017). The additional ideas generated after this phase were rated as higher in novelty, specificity and relevance (Gray et al., 2017). Morphological analysis (exploration of possible solutions using matrix model) (Allen, 1962; van Schie et al., 2009), value engineering (an function examination to improve the value of products) (van Schie et al., 2009), rapid prototyping (van Schie et al., 2009), use cases
and pluralistic walkthrough (idea development with a demonstration of prototype based on user action sequence) (van Schie et al., 2009), role-playing (van Schie et al., 2009), and what-if scenario building (A Liem & Sanders, 2013) have been suggested to optimize and to improve a second round of ideas from a set of initially generated ideas.

**Discussion:**

The discontinuous (innovative) NPD Process Model which shows technology driven approach (Veryzer Jr., 1998), and the HCD process model which is closely related to ergonomics (“User-Centered Design Basics | Usability.gov,” n.d.), are presented adjacent to each other to suggest how the HCD process model may help the front end of technology driven NPD process in Figure 16. Figure 16 also captures the methods and tools documented in the literature. The visualization of the methods and tools found in the literature adjacent to the NPD and HCD process models suggests where they may be useful in the front end of the technology driven NPD process. The methods and tools can be separated into two categories: 1) directly aiding the technology driven NPD or 2) potentially helpful to aid technology driven NPD. These categories are identified as “Tech. driven NPD” and “NPD” in Figure 16. Within Figure 16, two distinctive icons were used to differentiate whether or not the methods and tools support user/customer involvement.
Figure 16. A matrix of methods and tools to support a technology driven NPD process.

In addition to the methods and tools, the literature reviewed for this paper addresses topics relevant to the technology driven NPD process which should be brought into this discussion. Technology is noted as being one of the three main levers (form, mode of use, and technology) of the design-driven NPD process (Rampino, 2011). Technical research along with
observational research and interviews is central to developing innovative products (Albayrak et al., 2009). Due to designer’s lack of technological knowledge, conceptual functions suggested by designers may not be possible or feasible to develop (Haritaipan et al., 2018). This lack of feasibility often results in engineers, who are less concerned with user experience during product development, being in charge of product conceptual development and designers being in charge of products appearance (Haritaipan et al., 2018). Thus the importance of improving technology literacy for designers is underscored (Blanco et al., 2017). Some of the methods and tools documented in the literature that aid idea generation from technology may help designers to improve their technology literacy.

Previous studies noted challenges when teaching novice designers, engineers and students to apply design methods and tools in a technology driven NPD and NPD process [16, 46]. First, human centered design methods used in the fuzzy front-end are difficult to teach in education settings due to the short timeline and lack of prior experience of the students (A Liem & Sanders, 2013). Second, it is difficult for students to transfer the user-centered research results to design inspiration (A Liem & Sanders, 2013). Third, while students think design methods are useful for innovative product development, they tend not to use design methods because of the effort required to understand how and when to implement design methods within a given time frame (Miller & Summers, 2013). Finally, applying design thinking, a complex and holistic approach, to technology driven NPD is difficult to implement in traditional education lectures or seminars (Pavel & Berg, 2015). Studies suggest situating students in a practice-based studio learning environment (such as capstone model), allowing them to work with design experts and working on complex, real-world problems will enhance students’ understanding of the design methods and tools (Miller & Summers, 2013; Mubin et al., 2017; Pavel & Berg, 2015). This
approach may help students learn how and when to use the methods and tools during the
technology transfer at the front fuzzy end of technology driven NPD. Thus, effective design
methods, tools and education programs need to be more accessible and structured for novice
designers and engineers. Future studies need to investigate how design methods and tools can be
effectively taught to design students enabling their active engagement in technology driven NPD
once they graduate and are in practice.

Also, papers mentioned that the additional help and education will be needed for
practitioners including designers and engineers (B. S. Yoon & Jetter, 2015). Studies addressed
that there will be friction within companies while embedding design in NPD (Malmberg &
Holmlid, 2014) because of the difference in perspectives between experts (e.g. technologists and
designers) (Blanco et al., 2017). In other words, it takes some time for design to fully and
effectively make contribution when developing innovative products (Malmberg & Holmlid,
2014) in technology driven NPD. Over reliance on customer involvement results in merely
incremental innovation (K. M. Kim & Lee, 2016; Norman & Verganti, 2013; B. S. Yoon &
Jetter, 2015); thus the tools and methods integrating customer input in NPD need to balance
customer perspectives with technological possibilities (B. S. Yoon & Jetter, 2015). Since
sometimes new ideas occur spontaneously outside of a development process (Hakansson & Ford,
2002), the over use of design methods and tools in technology driven NPD would have a
negative effect on product innovation. Since the front end of NPD needs to be fast for companies
to remain competitive, the methods and tools used in the early phase of NPD need to be updated
and effective in a limited time frame. While there are many studies regarding utilizing design
methods and tools used in NPD process in engineering and design management, there are few
publications documenting the assessment of design methods and tools in the design field.
Additional design research investigations are necessary for design researchers who are updating methods and tools to effectively aid designers in the technology driven NPD.

There are limitations regarding this systematic literature review. The journals that the author reviewed were focused on design, design education, technology, and ergonomics; key journals from related fields could be reviewed in future studies. Since the review was focused on peer reviewed papers and their associated citations, conference proceedings and book chapters from related fields also need to be identified and synthesized. The usefulness and effectiveness of the methods and the tools were not evaluated in this study. Future studies are needed to evaluate the usefulness and effectiveness of the methods and tools used in the front end of technology driven NPD process.

This systematic literature review presents the documented design methods and tools that have been developed and used in technology driven NPD process. The findings are categorized into the following themes: 1) the role of design in technology driven new product development and innovation; 2) the methods and tools to support user involvement at the front end of technology driven NPD; and 3) the methods and tools for innovative idea generation from technology. Figure 16 presents when each method and tool can be used in the technology driven NPD process. Design researchers can use these empirically tested methods and tools to specify the context of use and requirements, to generate innovative ideas, and evaluate designs in the front end of technology driven NPD process. These design methods, tools and education programs needed to be updated and new ones developed to be effective, accessible and structured for both designers and engineers involved in the technology driven NPD process.
CHAPTER 3

CASE REVIEW OF AUTHOR’S DESIGN PROJECTS

Introduction

The author has been working in the industry as a designer for nearly 4 years in total and has completed 11 projects with different organizations, including Hanes Brand, Machine Olfaction Laboratory, the Defense Advanced Research Projects Agency, JLG Industries, General Motors, LG, Burt’s Bees, Samsung, Paradigm Innovation, and Duke Institute for Health Innovation. This synthesized work experience as a designer is visualized in Figure 17. In the visualization, each project is categorized as technology-driven approach, market-driven approach, or design-driven approach with different icons. Each project is color-coded in blue and red to identify the projects that 1) the author worked on with confidence or 2) were challenging to the author. The author’s status as a student designer, freelance designer, or full-time designer are indicated per project with different icons. The size of the organization, either big or small, is also indicated with different icons. Finally, the summary of each project’s brief is described under the name of the project.
Figure 17. Synthesis of the author’s work experience in industry as a designer.

Results

The projects that the author 1) working on with confidence or 2) was challenged by are visualized separately in Figure 18 and Figure 19 to synthesize 1) the different approach types (technology-, market-, or design-driven approach), 2) the size of the organization, and 3) the reasons for feeling either confident or challenged while working on the project.

Regarding the approach of the projects, the author worked confidently on 1) three design-driven projects (in large scale organizations), 2) two market-driven projects (one large scale and one small scale organization), and 3) one technology-driven project (large scale organization).
The projects that were challenging to the author were 1) four technology-driven projects (three large and one small organization) and 2) one design-driven project.

The reasons for having confidence while working on the projects (color-coded as blue in Figure 17) were as follows. First, most of the projects, besides the Health Innovation consulting project for Duke Institute, followed the conventional design process, methods, and tools that the author had learned from his design education. Also, the technologies applied to the projects were either already familiar to the author or not difficult to understand. Since the author was confident in working on the project, his role as a designer in the project team was expanded. For instance, in the Paradigm Innovation Remora project, even though the author was working as a freelance designer, he ended up leading the conversation during the concept design phase, and the results of the project were recognized as an award winner at the Enactus National Competition in San Francisco in 2018.

The reasons behind the projects being challenging to the author (color-coded as red in Figure 17) were as follows. First, it was hard to understand the technology the author was asked to apply to product ideas. Also, it was hard to envision a useful scenario for the advanced technologies applied in everyday life because the technology had not yet been used for the public. In addition, it was hard to work with other disciplines, especially scientists and engineers. Finally, especially on the General Motors “Cadillac lighting system” project, it was a heavily aesthetic-focused project, specifically focusing on the components of vehicle design. While the students majoring in transportation design were familiar with the aesthetic-focused design process, it was unfamiliar to the author, who had received a conventional industrial design education, which does not cover the process of vehicle design. Since the author was not confident in working on the projects, his contribution to those projects as a designer was limited,
such as merely 1) visualizing other’s ideas, 2) working on aesthetic aspects of the product, and 3) designing presentation slides. The summary of the results regarding the projects that the author worked on either confidently or with difficulties is visualized in Figure 18 and Figure 19.

**Figure 18.** Synthesis of the projects worked on with confidence.
Figure 19. Synthesis of the projects worked on with difficulties.

The author’s work experience in industry as a designer is synthesized on the summarized map of literature review (Figure 15) to map an empirical example of how the current design education model responds to the role of design(ers) in industry (see Figure 20). The map is discussed in the following section.
Figure 20. The contribution of design education to the author’s work experience.
Discussion

There are several findings based on the synthesized map (see Figure 20). First, design education in the past, which focused on teaching art and craftsmanship and how to design functional and manufacturable products, has made contributions to many projects in recent years. Second, educating students in design thinking has also contributed to most projects. However, the cultivation of interdisciplinarity seems to be missing in design education. For instance, the Machine Olfaction Laboratory project was challenging for the author due to the difficulties of working with engineers. This implies that the ability to work with other disciplines, especially with engineers, would be crucial for the author to maximize his contribution to projects as a designer. Finally, as shown in Figure 20, while at least one aspect of design education made contributions to each of his projects, the author nevertheless felt that five of the projects were challenging. This implies that it would have been helpful if the author had had the opportunity to receive additional design education regarding technology and engineering-related knowledge. This would have altered the challenging work experiences (having difficulty understanding the technology, which is associated with the difficulty of working with engineers) into positive and confident experiences. Also, increasing his ability to understand technology would have helped the author to communicate more effectively with engineers and scientists.

Although the “LG HomeChat” project was categorized as a challenging project, the utilized design methods and tools, such as user persona and modified user journey map for the project, were helpful in moving it forward. By utilizing these methods and tools, the author was able to envision possible user scenarios for the given technology (i.e., to potentially improve the end user’s quality of life by applying text-based interactions with IoT technology to home appliances). In addition, this LG project enabled the author to gain in-depth knowledge on IoT
technology and its potential applications. This suggests that experience in technology-driven NPD in design education would have helped the author to actively contribute as a designer in the projects that were in a technology-driven context.
CHAPTER 4
PURPOSE OF THE STUDY AND RESEARCH DESIGN

Proposition Mapping

Craig Vogel, a design educator and healthcare innovator and entrepreneur, addressed the evolution of rapid technology in his keynote speech at the European Academy of Design (EAD) in 2019. According to Vogel, companies in industry have put in a considerable amount of effort to taking a technology-driven approach, either by focusing heavily on this approach or by at least partially putting their effort and budget towards it (Cooper et al., 2017).

However, the design education provided to the author (2005 to 2019) did not include design curriculum to educate designers in taking on roles with a technology-driven approach. Hence, educating design students regarding a design process that is beneficial for technology-driven NPD in addition to the current design education focus (empathy and human centeredness) would fill a gap for design students preparing them to actively take on a designer’s role in a technology-driven context. Also, teaching the design process of a technology-driven approach and letting students gain technology-driven design experience may help students to learn how to obtain key knowledge of the technology that can be transformed into product ideas. This might help design students to develop their ability to connect technological knowledge to creativity. Finally, since some design students have a fear of even understanding technology, having experience with a technology-driven NPD approach could lower the threshold for them regarding fear of learning new technology. This would potentially enhance their confidence in interacting with technologists and engineers, which would eventually improve the design student’s communication skills in an interdisciplinary work environment. The proposition of this dissertation study regarding how to improve design education’s contribution to the industry is
Educating design students (at least at university level) regarding how to

- understand advanced technology and
- apply the technology to product and service design

by having the experience of a technology-driven approach in school would improve the contribution of design education to the current industry.

The educational method (perhaps a course or workshop) that trains design students in this approach and gives them experience with the design process, methods, and tools in a technology-driven context will be referred as the “Technology to Product Design Process (TPDP)” in this study. The possible contribution of TPDP is mapped according to the author’s work experience as a designer (see Figure 21).

Since design methods and tools guide designers during the design process, a systematic literature review of design methods and tools for technology-driven NPD was conducted. The details of the literature review are shown in the section “Systematic Literature Review: Design Methods and Tools to Support a Technology-Driven Approach.”
As the systematic literature review results indicate, there are few design methods and tools currently available to aid designers in technology-driven NPD. Also, no literature was found describing the contribution of the design process in a technology-driven project. Hence, as illustrated in Figure 21, developing TPDP and educating design students on this process in addition to the content of the current design education model would contribute to extending the
role of designers in the industry. The purpose of this study is to 1) develop and update the design process, methods, and tools that aid designers at the front end of technology-driven product development and 2) develop a TPDP course that helps design students to experience TPDP and related design methods and tools to test the proposition described in Figure 21.

**Research Questions and Objectives**

The three research questions (RQs) addressed in this dissertation are shown below.

RQ1: How are design students and recent graduates currently educated to contribute their design ability to the technology-driven new product development (NPD) process?

RQ2: How has the designer’s role changed in contemporary Technology Driven Organizations (TDOs) and which design methods and tools were used in NPD projects?

RQ3: How to improve TPDP to be effectively taught to design students in educational setting?

**Methodology**

Three studies were conducted to answer RQ1, RQ2, and RQ3. First, to address RQ1, literature on the current design education model and activities that can aid a technology-driven approach was reviewed and surveys and interviews (Study 1 presented in Chapter 5) with ID professors, practitioners, and students were conducted. The design process, methods, and tools for TPDP were developed based on the literature, survey and interviews. Case studies (Study 2 presented in Chapter 6) were examined to understand the role of designers and the design process, methods, and tools utilized in technology-driven organizations and to address RQ1 and RQ2. TPDP and related methods and tools were identified, developed, and updated based on the
results of Study 2. Finally, expert reviews (Study 3 presented in Chapter 7) were conducted to evaluate the revised design process, methods, and tools for TPDP were conducted to answer RQ3. Each of the three studies are formatted as manuscripts for submission to the journals appropriate for publication (which are identified within each chapter).
CHAPTER 5

TECHNOLOGY-DRIVEN DESIGN PROCESS: TEACHING AND MENTORING

TECHNOLOGY-DRIVEN DESIGN PROCESS IN INDUSTRIAL DESIGN EDUCATION

Chapter 5 is formatted as a manuscript for the submission to the International Journal of Technology and Design Education.

Title: Technology-Driven Design Process: Teaching and Mentoring Technology-Driven Design Process in Industrial Design Education

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Abstract: There are two main approaches for new product development for innovation, either innovation originates from market and customer's needs (i.e. market and user-centered innovation) or from technology (i.e. technology-driven innovation). The Industrial Design (ID) education offers numerous opportunities for students to learn the market and user-centered approach; however, the discipline seems to lack curriculum in the technology-driven approach. Many companies focus heavily on the technology-driven approach or at least partially putting their effort and budget in it. Educating how to understand a technology and to apply the knowledge to the university students in ID program would improve the contribution of design education to the industry. The purpose of this study is to understand which processes and skill sets, including design methods and tools, are necessary to achieve successful technology-driven innovation and to generate ideas as to how these processes and skill sets can be translated into a curriculum that will help students quickly and readily transition into the job market.

A grounded theory approach was used to understand how design educators and practitioners teach, guide, and mentor ID students and novice industrial designers. Primary
(syllabi and class activities about Technology-driven design process) and secondary (semi-structured interviews and surveys) data were collected and reviewed to understand 1) ID educators’ and practitioners’ teaching/mentoring experience in technology-driven design projects and 2) ID students' and recently graduated students' experience in technology-driven design projects. Synthesizing both primary and secondary data led to the development of a technology-driven process model that will help to guide how to teach and mentor ID students and novice designers within a technology-driven context.

Introduction

There are two main New Product Development (NPD) approaches to achieve innovation — market-driven and technology-driven (Chaudhary, 2005; Ettlie & Subramaniam, 2004; Veryzer Jr., 1998). The market-driven approach is defined as developing a new product based on the value that customers are interested in (Vorhies et al., 1999). The technology-driven approach is defined as the NPD depended on technology ("technology-driven Definition in the Cambridge English Dictionary," n.d.). The technology-driven approach drives companies to focus on investing in the research and development of technology to enhance its capabilities in order to differentiate their products and services from competitors (Berman & Hagan, 2006; Gatignon & Xuereb, 2016; Rosenberger & Kathleen, 2015; Zhou et al., 2005).

The technology development process and technology-driven NPD process are two separate processes (Keersmaecker et al., 2012). While technology development focuses on developing the state of art technology, technology-driven NPD focuses on developing a new and innovative product. The front end of the technology-driven NPD process includes the transition from technology development to product development. The transition is referred to as
“Technology Transfer (Keersmaecker et al., 2012).” Since the role of design has been expanded during the NPD process, there is the potential for design to take a role during the technology transfer phase.

A technology-driven firm is a company that has a clear focus on developing technology-related R&D products and uses technology as a source for developing future products (Hao & Song, 2016). Based on previous studies, a large portion of the companies pursuing discontinuous NPD (i.e. from the development of button type cellular phone to the development of a touchscreen smartphone), also known as innovative NPD, tend to take technology-driven approach (Ali, 1994; Veryzer Jr., 1998). “Design, the value” report in 2016 illustrates that almost 28% of companies in the UK take a technology-driven approach, rather than a market-driven approach. In other words, those companies focus more on “developing technologies and then seek markets for them” rather than focusing on “identify market needs first and then source the technologies for it (Cooper et al., 2017).” Base on previous studies, there are benefits for companies to take a technology-driven approach (Hao & Song, 2016). First, technology-driven firms tend to have higher product performance (Braguinsky et al., 2012; Eesley et al., 2013). Second, the products developed by technology-driven firms compete well with their competitor’s products in the market because their products are technologically superior (Gatignon & Xuereb, 1997; Hurley & Hult, 1998; Song & Parry, 1997). Third, the technology-driven approach enables firms to enter a new market and to deliver products to market rapidly because it skips the lengthy, traditional market research (Mu & Di Benedetto, 2011). Finally, discontinuous innovation are strongly associated with technological advance (Ali, 1994; Maarse & Bogers, 2012; Tushman, 1997). In order to develop such (discontinuous) products, “managers find specific uses or markets for a promising new technology” (Ali, 1994).
As there has been an increasing number of multidisciplinary, interdisciplinary, and transdisciplinary projects and research studies, within universities, Design departments collaborates with other departments including Electronic Engineering, Computer Science, and Industrial Engineering to develop new products. Nowadays Industrial Design (ID) students have increased opportunities to interact with Engineering departments to develop new product ideas. The ID education offers numerous opportunities for students to learn the market and user-centered approach; however, the discipline seems to lack curriculum on the technology-driven approach. Because of the reason, while ID students are familiar with the NPD projects initiated by users' needs, many students lack confidence when collaborating with those outside their field on technology-driven NPD projects.

**Proposition Mapping**

Teaching design process using a technology-driven approach and letting students have technology-driven design experiences may help students learn how to obtain the critical technological knowledge and confidence that they transform technologies into product ideas. Since some design students have a fear of understanding new technologies, having an experience with a technology-driven NPD approach within their curriculum could lower the barrier to learning about new technologies. This may enhance their confidence in interacting with technologists and engineers and improve the design student’s communication skills in an interdisciplinary team environment. The contemporary industry is moving toward to the 4th Industrial Revolution, which includes the emergence of breakthrough technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing.
Having technology literacy will benefit ID students allowing them to integrate these cutting-edge technologies in the products they design.

A proposition with regards to improving the contribution of design education to the contemporary industry evolved. Educating design students (at least at university level) including 1) understanding advanced technology and applying the knowledge from the technology to everyday life and 2) having a technology-driven approach academic experience would improve the contribution of design education to the contemporary industry. While there are a number of methods and tools taught in design education to support market and design-driven NPD, a relatively smaller number of documented studies were found regarding the design methods and tools that support the process of technology-driven NPD (B. Kim & Joines, 2019). Also, there are few studies documenting the teaching of the design process in a technology-driven approach in ID education.

The purpose of this study is to understand important processes and skillsets, including design methods and tools, supporting technology-driven innovation in NPD that are currently being taught in ID education. The results of this study will contribute to generating ideas about how these processes and skillsets can be translated into a curriculum that will help ID students quickly and readily transition into the job market. Thus, the main research question is: how are design students and recently graduated students currently educated in order to contribute their design ability in a technology-driven NPD process?

**Research Strategy and Design**

This study takes a Grounded Theory Approach (Bryant & Charmaz, 2007) which consists of question identification, data collection, data synthesis, and knowledge construction.
**Methods:** Surveys and interviews were conducted with ID educators, practitioners, and ID students and recent graduates to understand 1) how design education currently teaches students about how to understand and apply technology into the product design process, 2) the participants’ technology-driven NPD experience working with technology companies, and 3) challenges and concerns in terms of learning technology-driven NPD approach in ID education.

The assessment of the surveys (see Appendix B) and interviews (see Appendix C) includes: 1) the participant’s perception regarding the importance of technology-driven product development in design; 2) the participant’s opinion regarding the current status of teaching/mentoring technology-driven approach in design program (i.e., the level of student's readiness to work on technology-driven design process); 3) participant’s experience with technology-driven design projects; 4) tips to learn the technology-driven design process; 5) challenges with and/or suggestions for teaching/mentoring/learning technology-driven approach; and 6) sketches of the important aspects of the technology-driven design process. The study plan was reviewed and approved by the Institutional Review Board (IRB) at North Carolina State University (see Appendix A).

**Data Collection:** The surveys and interviews were conducted with individuals from different countries. Surveys were conducted in the U.S., Canada, Korea, Taiwan (Republic of China), and China. The interviews were conducted with individuals from the U.S., Canada, and Korea. As English is not the first language in some of the countries for this study, the study materials were translated into Chinese and Korean. The interviews with students and recent graduates were conducted in English. Thus, those participants needed to be fluent in English. The study materials in English were initially translated by researchers and design practitioners fluent in English and Korean, and English and Chinese. The drafted translated materials in
different languages were compared with the English version by the various bi-lingual researchers and practitioners and the translations were reconciled.

ID programs and the courses being taught in the programs (undergraduate level) in the targeted countries were reviewed to identify design educators who teach the application of technology in design in universities. The identified design educators whose contact information is publicly available (i.e. email address and/or social networking websites) were contacted to participate the study. Similarly, the researcher reviewed technology companies. The designers who have ID background, currently/Previously work/worked for the technology companies, and have publicly available contact information (i.e. email address and social networking websites) were contacted about participating the study. Design educators, who the researcher already knew to have taught or were currently teaching course(s) regarding the technology-driven process, were contacted to disseminate the recruitment email to recruit their students for the interview.

At the end of the surveys and interviews, the design educators who participated in this study were asked to share their syllabi and class activities through which they taught and guided technology-driven design projects. Five syllabi and related class activity materials were collected and reviewed.

**Participants:** For design educators and practitioners, the survey and interview participants needed to have enough working/teaching experience to enable the researcher collect valid data. The inclusion criteria was: 1) designers need to have at least three years of working experience in technology companies or involved in technology-driven NPD projects; or 2) design educators need to have at least three years of teaching experience, either in a project-based learning environment (also known as studio) or in lecture-type classes.

For students and recent graduates, interview participants were students or recent
graduates (within 5 years) from an ID program; have had experience learning and/or working on technology-driven design projects in school; and were fluent in English.

Design educators and practitioners who the researcher already knew were contacted to take part in the study; snow-ball recruitment strategy was also used. Data from participants who completed more than 80% of the survey (n=33) and those who completed the interview (n=22) were synthesized for this study (see Table 4).

Table 4.  
_The number of study participants._

<table>
<thead>
<tr>
<th></th>
<th>Survey</th>
<th>Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID Educators</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>ID Educators with Practice</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Practitioners</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Students and recent graduates</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
</table>

**Procedures:** Online surveys were conducted via Qualtrics. Participants used either their computer or phone. After consenting to participate in this study, participants were asked to complete the survey which included questions regarding demographic information, working/teaching experience, and the importance of understanding technology in the design process. There were 15 questions in the survey which took ~40 minutes.

The interviews were conducted either in-person or via video conference call. To capture their understanding of the technology-driven design process, participants were asked to draw a design process. While the participants answered questions, the researcher took notes during the interviews. The syllabi and related materials were collected, from those who were willing to
share, to capture the participant’s process and activities used for the technology-driven design classes.

**Data Analysis:** Textual analysis was used to synthesize the data from the survey and interviews for thematic analysis including: 1) reading the notes and written survey responses; 2) labeling relevant pieces (coding), either explicitly or implicitly; 3) deciding which codes were most important; 4) creating categories by bringing several codes together; 5) labeling categories; and 6) determining which were most relevant and how they were connected. (Bryman, 2012; Charmaz, 2006; Kvale & Brinkmann, 2009). MAXQDA 2020, a software program for computer-assisted qualitative data analysis and Post-ItTM notes were used for thematic analysis. After the thematic analysis, the coded data, themes, and categories were reviewed by two design researchers unrelated to this study 1) to consider whether the coded data and themes form a coherent pattern and 2) to determine whether the themes accurately reflect the meanings in the data set (Braun & Clarke, 2006). Figure 22 and Figure 23 depict the data synthesis process in MAXQDA using screenshots and manual sticky notes using photos.

The collected syllabi and related activity materials were synthesized to understand the general technology-driven design process taught to students based on the description of the weekly activities. The materials for the weekly activities were synthesized and located within the synthesized general process.
Figure 22. Thematic analysis tool: MAXQDA (screen-captured from the researcher's computer).

Figure 23. Thematic analysis tool: Adhesive notes (the researcher's workstation).
Results

From the surveys and interviews seven themes and multiple categories under each theme were developed from the collected data.

Table 5 presents the overview of the study results, including themes and categories. From the syllabi and activity materials review, four different high-level steps were identified including: 1) introduction, 2) a product opportunity identification, 3) product concept and marketing development, and 4) storytelling and lessons learned. The detailed activities associated with the steps are shown in Figure 24.

Table 5. *Study results overview.*

<table>
<thead>
<tr>
<th>Themes</th>
<th>Categories (number of mentions/number of participants mentioned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Importance of Technology in Design</td>
<td>Important: Winning competition (23/23)</td>
</tr>
<tr>
<td>Technology in Design Process</td>
<td>Important: Technology as a tool (12/7)</td>
</tr>
<tr>
<td></td>
<td>Important: Collaboration with other disciplines (9/9)</td>
</tr>
<tr>
<td></td>
<td>Important: Feasibility (3/3)</td>
</tr>
<tr>
<td></td>
<td>Important: Learning from diverse experiences (2/2)</td>
</tr>
<tr>
<td></td>
<td>Not important: Needs/imagination over technology in design process (12/9)</td>
</tr>
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<td></td>
<td>Not important: Only a sub element of NPD process (11/10)</td>
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<td>Table 5. (continued).</td>
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<tr>
<td><strong>Student’s Readiness:</strong></td>
<td>Ready: Enough Current education to teach technology-driven approach (6/6)</td>
</tr>
<tr>
<td><strong>Technology-driven Approach Application in Design Education</strong></td>
<td>Not ready: Gap between education, student needs, and practice (15/13)</td>
</tr>
<tr>
<td></td>
<td>Not ready: Overly specific technology (6/6)</td>
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<tr>
<td></td>
<td>Not ready: Lack of multidisciplinary experience (4/4)</td>
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<td></td>
<td>Out of design educator’s ability (2/2)</td>
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<td></td>
<td>Depending on instructors (2/2)</td>
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<tr>
<td><strong>Ideal Pedagogical Approach</strong></td>
<td>Corporate-funded projects (9/9)</td>
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<td></td>
<td>Developing new courses (7/7)</td>
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<td></td>
<td>Internships (6/4)</td>
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<td></td>
<td>Prep-learning for technology-driven design projects (2/2)</td>
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<td></td>
<td>Optional class (2/1)</td>
</tr>
<tr>
<td><strong>Experience of Technology-Driven Design Projects</strong></td>
<td>Design development (18/24)</td>
</tr>
<tr>
<td></td>
<td>Direction and idea exploration (7/3)</td>
</tr>
<tr>
<td><strong>Tips for Technology-Driven Process</strong></td>
<td>Considering different technology aspects and beyond (15/8)</td>
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<td></td>
<td>Considering the importance of instructor’s role (10/7)</td>
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<td>Utilizing methods (9/6)</td>
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<td>Empathizing the importance of user-centered design (8/7)</td>
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<td>Maximizing motivation (8/7)</td>
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<td>Maximizing team engagement (7/5)</td>
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<td></td>
<td>Understanding of overall NPD process (6/4)</td>
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<td></td>
<td>Utilizing idea generation techniques (3/2)</td>
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<tr>
<td>Challenge/Concerns of Teaching Technology-Driven Approach</td>
<td>Technology application limit (29/24)</td>
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<td></td>
<td>Collaboration with different disciplines (22/10)</td>
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<td>Unusual design process (11/10)</td>
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<td>Project administration (8/7)</td>
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<td></td>
<td>Dissent in group work (5/3)</td>
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<td></td>
<td>Funded projects limit (4/4)</td>
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<td></td>
<td>Lack of motivation (1/1)</td>
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<table>
<thead>
<tr>
<th>Important aspects of the technology-driven design process</th>
<th>Decision making (9/9)</th>
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<tbody>
<tr>
<td></td>
<td>Project kick-off (3/3)</td>
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<td></td>
<td>Direction exploration (27/21)</td>
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<td>Idea development (14/10)</td>
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Figure 24. Overview of the technology-driven design related activities in the current ID education (based on syllabus review).

The Importance of Technology in Design Process:

During the survey, the instructors, practitioners, students and recent graduates were asked to answer the question, “How do you personally rate the importance of the finding the
application of technology to product ideas (e.g., finding an opportunity to apply VR technology to develop products and services)?,” by choosing one of the five ratings (very important, important, so-so, less important, or not important). The survey participants were also asked to provide reasons to support their answer. The interviewed participants were asked to answer the same question without the ratings. Figure 25 synthesizes the results from the survey ratings, along with related reasons from the collected data from the surveys and interviews.

Figure 25. Overview of study participants’ perceptions regarding the importance of technology in the design process.

Important:

Winning competition: Educators (n=11), practitioners (n=11), and a student responded that it is vital for companies to focus on technology-driven approaches in the design process, as the approach can help develop competitive products by connecting technology to users’ needs through discontinuous innovation. For instance, a practitioner commented that “New and unique
technology sets you apart from the competition and also enhances user experience if approached from the user perspective.” Also, another practitioner mentioned that the application of new technology gives us the opportunity to create new products and services rather than just improve on existing ones.

Technology as a tool: An educator and students (n=6) responded that technology is a useful tool during the design process, including: 1) to simulate different possibilities and interactions between humans and products (i.e., using VR to explore different scenarios); and 2) to test out concepts. These respondents also mentioned that industrial designers need to stay on top of technology as a tool and not as the main driver. Students mentioned that understanding manufacturing technology is helpful with the idea development and with refinement in the design process.

Collaboration with other disciplines: Educators (n=6) and practitioners (n=3) responded that it is beneficial for students to have technology literacy to enhance the students’ ability to collaborate with other disciplines, especially with engineers and technologists. For instance, one of the educators from the survey responded that through the technology-driven design process experience, students could learn how to collaboratively solve advanced challenges based upon technology applications and design integration, market research, as well as form-giving for product innovation. Another educator mentioned that design education needs to understand the big picture in NPD process and the designer’s role in technology-driven NPD. Finally, practitioners responded that it is crucial for the researchers and technologists working for a large technology company to show the value of the technology to the decision-makers of the company.

Feasibility: An educator and students (n=2) mentioned that it is essential to understand the limitations of technology to define how far designers can go to meet NPD goals. For
instance, in the survey an educator commented that “without supported technology, the design is a concept idea only. The important key for me as a professional designer is how to make harmony between technology and design.” A student also mentioned that understanding technologies would help designers being able to see certain user scenarios.

*Learning from diverse experiences:* Students (n=2) mentioned that they are open to diverse learning experiences and were interested in learning new design processes and approaches, such as the technology-driven design process. For some students, the technology-driven approach sounds different from a user-driven approach, and the students were interested in a deeper understanding of the approach. Also, students mentioned that learning new manufacturing technology was beneficial in integrating the technology into their current ID process. Similarly, students also mentioned that diverse knowledge about advanced technologies would help them to achieve product innovation. Students also remarked that it is important to understand the rapid technology evolutions that are relevant to ID, such as VR, AR, UI, and UX technologies, and how to integrate the technologies into the design.

*Not Important:*

*Needs/imagination over technology in design process:* Educators (n=6) and practitioners (n=3) suggested that technology-driven approach is not an ideal NPD process. They emphasized the importance of story and imagination, rather than technology. For instance, two educators from the survey opined that while sometimes new technology will suggest new solutions or opportunities, it was not important to finding "homes" for new technology as often times this becomes an effort to force-fit technology into areas solely for the use of the technology.

*Only a sub element of NPD process:* Educators (n=6) and practitioners (n=4) responded that while technology is one of the important factors to consider in NPD to make a successful
business case, it is not the main driver of NPD. For instance, two educators from the survey responded that while technology is necessary in the NPD process, technology should be only considered as a tool and only be used when the business cases and product intent require it.

**Student’s Readiness (Technology-driven Approach Application in Design Education):**

During the survey, the instructors, practitioners, students and recent graduates were asked to answer the question, “How well does current design education/training prepare designers to develop a product starting from advanced technology that meets the market/user need?” The survey participants were asked to choose one of the five given ratings (The students have been very well/fairly well/somewhat/poorly/not prepared). The survey participants were also asked to provide reasons to support their answer. The interviewed participants were asked to answer the same question without the ratings. Figure 26 shows an overview of the rated results from the survey responses, along with related reasons from the collected the survey and interview data. The qualitative data from the survey and interview responses were divided into “ready” and “not ready” Based on the tone. For instance, while one survey participant chose that “the students have been fairly well prepared,” if the participant’s comments were mainly about what are lacking to have the students to be more ready, the qualitative data set was categorized as “not ready.”
Figure 26. Overview of the study participants’ perceptions regarding the ID student’s readiness.

**Students Ready:**

*Enough Current education to teach technology-driven approach:* Educators (n=6) responded that current ID education is enough to teach students because 1) user-driven approach covers most NPD process; 2) the current design education has been improved compared to the past; and 3) the students are well exposed to technology, users, and society to be the designers who can adapt themselves in different NPD approaches.

**Students Not Ready:**

*Gap between education, student needs, and practice:* Educators (n=4), practitioners (n=6), and students (n=3) mentioned that there is a gap between design education and practical needs because 1) education is a generation behind students’ needs (e.g. it is out-of-date) and 2) a pedagogical environment is not the same as the real world. One of the educators from the survey commented that “it depends on which institution or program they (students) are involved in.” A student mentioned that some professors seemed to prefer a conventional design educational...
Another student mentioned that some younger professors are open to trying new teaching methods and tools compared to senior professors. Students also mentioned that there were not enough opportunities to learn technology even the very basic ones. For instance, even though students would like to learn UX related technologies and mechanical engineering related technology, there are no ways to find and enroll courses within a design department.

*Overly specific technology:* Practitioners (n=2), educators (n=2), and students (n=2) mentioned that it is difficult to learn specific technologies in school. They addressed that students can learn a certain technology after they were hired as designers in an organization. An educator from the survey commented that “Technology comprises of a large range of topics. For any area of study, it takes time to gain a proper understanding of the technology before you can apply it in a new, meaningful and market-ready way.” There are comments from students that learning a specific technology using the technology-driven approach was beneficial for their future design process. For instance, under a technology-driven approach, a student noted that there was a class that the student took to learn the thermoforming process to understand how plastic behaves in this manufacturing technology. The student mentioned that the class was beneficial as the technical knowledge was applicable to other studio classes. The other student mentioned that learning multiple manufacturing-related technologies would be helpful since having the technical expertise would be beneficial in the ID field.

*Lack of multi-disciplinary experience:* Educators (n=2), a practitioner, and a student responded that students possess a lack of experience in working with non-designers. One of the educators from the interview mentioned that ID students (graduate level and some selected high achievers from undergraduate students) would not have much problem working with certain engineering departments, such as mechanical and industrial engineering. Still, it would be
difficult to work with a computer science department, as there is less common ground, and the students are not familiar with coding and basic computer science-related knowledge.

*Out of design educator’s ability:* Practitioners (n=2) mentioned that students are prepared based upon their own interest, not based on the education they receive. The practitioners addressed that if students seek out to learn technologies and the application of the technologies, they will learn what is available.

*Depending on Instructors:* Students (n=2) addressed that while some educators guide and teach the technology driven design projects in details, some are letting students to figure out the application of technology to product ideas.

**Ideal Pedagogical Approach:**

The survey and interview participants were asked “What pedagogical approaches or mentoring techniques do you think works best to teach students about how to achieve an innovation starting from the technology needed to develop products that the public want?” Figure 27 illustrates an overview of the results from the surveys and interviews.

**Figure 27.** Overview of an ideal pedagogical approach.

*Corporate-funded projects:* Educators (n=4), practitioners (n=4), and a student mentioned that practicing the application of technology in an NPD project model with actionable items that students can follow would be ideal for learning technology-driven design process. This type of
learning provides a hands-on experience to learn the designer’s role and contribution to the technology-driven NPD process.

**Developing new courses:** Practitioners (n=2) and educators (n=3) mentioned that some design students and novice designers do not have a good understanding of the overarching NPD process. Students (n=2) mentioned that it would be helpful to learn the technology-driven design process prior to engaging in sponsored projects from technology companies. Students also addressed that learning the technology-driven design process will prepare students to be professional designers who can think systematically when working on projects driven by technology.

**Internships:** Educators (n=3) and a practitioner mentioned during the interview that the best way of learning specific technologies related to certain companies is by interning for those companies.

**Prep-learning for technology-driven design projects:** Students (n=2) mentioned that having a studio (non-funded) project with less restriction would be beneficial in learning the process, rather than having to meet all the strict requirements and tight scope defined by technology companies in their first experience.

**Optional class:** One student mentioned that workshops that introduced related technologies (i.e., 3D printing and Arduino) were helpful. The student also stressed that elective courses to learn about certain technologies would help to teach students interested in certain technologies.

**Others:** An educator mentioned that the cooperative labor model, such as working in a team, would improve collaboration skills. A practitioner mentioned that considering feasibility, viability, and desirability in the design process would help students to deliver the outcomes of
any projects for a successful business case. Another educator pointed out that selecting a meaningful and relevant challenge for students would be a source of motivation during the class.

**Experience of Technology-Driven Projects:**

The collected data from the surveys and interviews about the participants’ experience regarding technology-driven design projects was synthesized and categorized. The projects were categorized as direction and idea exploration and product development. Figure 28 presents an overview of the synthesized results.

*Figure 28. Overview of the participants’ experience of technology-driven design projects.*

*Design Development:* Educators (n=10), practitioners (n=4), and students (n=10) mentioned their technology-driven design projects under design development. Design (or technology-driven product) development in this study is defined as developing new product concepts, including ID project outcomes, such as working prototypes and/or photo quality
renderings. For example, a student reported having worked on an interdisciplinary project to utilize a new sensor technology to detect leaks in the drains on the road to determine the level of water through the sensor. The outcome of the project was to design a sign and UX for drivers to avoid a detour.

*Direction and Idea Exploration:* An educator and practitioners (n=2) mentioned their technology-driven design projects under direction and idea exploration. Direction and idea exploration in this study is defined as follows: 1) identification of design topics and potential users and 2) exploration of technology application to product ideas. Direction and idea exploration do not necessarily include typical ID project outcomes, such as working prototypes and photo quality renderings. For instance, a practitioner worked on creating abstracts of the product ideas using the new material, so that the client, management, and other designers would be able to personally experience the story behind the material.

**Tips for Technology-Driven Process:**

The collected data regarding tips for technology-driven processes were synthesized and categorized. Figure 29 presents an overview of the synthesized results.
Considering different technology aspects and beyond: Diverse aspects of the given technologies considered by educators (n=3) and practitioners (n=5) included: 1) technology classification; 2) level of application of technology to product idea; 3) connection to end-users; and 4) unintended consequences of technology application. Some also mentioned that designers should go beyond the technology, such as technology and related politics, usefulness and profitability, and technology and society, to generate a product development road map and potential user scenarios.

Considering the importance of instructor’s role: Educators (n=5) and practitioners (n=2) agreed that the instructor’s role is crucial to successfully guide students during technology-driven design projects. An instructor, experienced in technology driven NPD instruction, mentioned that when exploring the different use cases of the technology, preparing the examples of use-cases to initiate a discussion session with students is beneficial to guide the students at the front end of
the project. Educating non-design major students about the importance of design and users in NPD was also addressed in interdisciplinary team projects to help design students to address the importance of UCD and the designers’ role in the NPD process to their non-designer team members. Since design students are often intimidated by technologies and reticent to ask questions to engineering students and technologists, one educator noted it is important to remind ID students about what ID can bring the value of products during NPD.

**Utilizing methods:** Students (n=6) identified the methods related to engaging with users and how to learn technology including: 1) defining potential users and conducting user research — such as having interviews and observation; and 2) engaging with professional designers were beneficial for finding unique opportunities and the progress of projects.

**Empathizing the importance of user-centered design:** Educators (n=5) and practitioners (n=2) responded that it is important for designers to find compelling users’ needs before generating design ideas. Defining potential end-users and receiving feedback from them helps achieve user-centered design ideas within a technology-driven context. The benefit of making an emotional connection between the given technologies and the end-users was also highlighted. One educator also noted that it would be beneficial for students to receive feedback from potential users in order to verify their direction and the usage technology.

**Maximizing motivation:** Connecting familiar users, such as the students’ family and friends as potential users for the given technology, giving a valuable learning outcome, and not to give too specific technology was suggested by an educator, practitioners (n=3), and students (n=3) to help motivate students to engage in the technology-driven design projects.

**Maximizing team engagement:** Students (n=5) noted their teamwork experience was heavily depends upon having good and supportive teammates, building trust within a team,
having the team on board with design ideas, and having teammates that understand the value of ID and end-users. Students also mentioned that the introductory lecture from ID professors to emphasize the importance of ID and users in the product development process was helpful in aligning the common goal at the front end of NPD with non-design students. One student mentioned that it was difficult to be the only designer in the team; it would have been better if there were at least one more design student on the team.

**Understanding the overall NPD process:** An educator and practitioners (n=3) addressed that it is important for designers to have a mental model and good understanding about the technology-driven design process and the multiple stakeholders involved in the technology-driven NPD process. For instance, practitioners highlighted that students understand the final experience, but they do not understand what it takes to get there (i.e. how something will go together and the reality of how users will interact with the technology). Also, practitioners noted that teaching the fundamental of technology driven NPD would be the first step to educate design students. Once students start understanding the overall process, students absorb and tend to apply the right design process for different technologies.

**Utilizing idea generation techniques:** Idea development methods mentioned by an educator and a practitioner included: 1) Triz, a problem-solving and forecasting tool to support technical innovation (Regazzoni, Pezzotta, Persico, Cavalieri, & Rizzi, 2013); 2) mash-up technique, combining more than two different elements to generate ideas (“Ideation Method: Mash-Up – IDEO U,” n.d.); and 3) random keywords combination tool (“Kombinator - A free tool for combining Google Ads keywords,” n.d.) suggested to be used for idea generation phase.
Challenge/Concerns of Teaching Technology-driven Approach:

The data regarding the challenges and concerns of teaching technology-driven approaches collected through the survey and interviews were synthesized and categorized. Figure 30 presents an overview of the synthesized results.

**Figure 30.** Overview of the challenges and concerns of teaching a technology-driven approach.

Technology application limit: The limitations of teaching technology-driven design processes in educational setting were addressed by both educators (n=13), practitioners (n=9) and students (n=2): 1) limiting product idea generation; 2) development of an actionable statement; 3) unstable design outcomes; and 4) difficulty in promoting the importance of design to other team members. Practitioners and students mentioned that if the class was a studio type, an additional challenge is that the outcomes of the course would not necessarily be the same as a course starting with users’ needs. For example, when a technology is not suitable for developing product course outcomes such as renderings and 3-D models are no longer relevant making for a
frustration for ID students who are focused inclusion of course projects in their portfolios.

*Collaboration with different disciplines:* Educators (n=3), practitioners (n=3), and students (n=4) addressed their challenges including: 1) difficulty working with some Engineering professors and students who focus on applying sensors in every product idea; 2) the design students’ lack of Engineering knowledge; and 3) communication barriers owing to technical terms and verbiage.

*Unusual design process:* Educators (n=4), practitioners (n=2), and students (n=4) raised their concern about the unfamiliarity of the technology-driven design process to students. Educators also mentioned that it would be different teaching engineering students how to design a product and teaching the application of technology in the design process to design students.

*Project administration:* Students (n=7) noted the challenges related to administration including: 1) too many students with little guidance from professors, 2) insufficient technology specific materials for prototyping, 3) not enough engagement with design experts, and 4) the same mentoring approach for graduate and undergraduate students. More specifically, students commented that there were not enough materials to study and build prototypes to understand the application of the innovative materials in product ideas. One student mentioned that there was only one chance for the ID students to collaborate with the other students from different disciplines during the class.

*Dissent in group work:* The challenges associated with team members from different disciplines were addressed by students (n=3). For instance, one student mentioned that it was difficult to promote the importance of design to non-design team members. Students also mentioned that it was challenging to brainstorm and generate ideas all by themselves since other team members did not value these activities. One student expressed frustration with user research
results not being applied to the final team deliverable at the end of the class.

*Fundled projects limit:* An educator and students (n=3) alluded to two main challenges of the project description and scope provided by technology companies when working on funded projects. Students commented that the project brief from an innovative material driven project was extensive then the students did not know where to focus in order to move the project forward. Another student admitted frustration over bigger issues that designers need to deal with; the student believed there would have been more opportunities if students could propose something else, other than what the company asked them to do.

*Lack of motivation:* The potential challenge of keeping students motivated and interested in learning a technology was highlighted by an educator. This challenge can be mitigated by applying the ‘motivation’ suggestions under ‘Tips for Technology-Driven Process.’

**Important aspects of the technology-driven design process:**

Participants were asked to sketch or write a description of the important aspects of a technology-driven design process that could help other designers learning the process. In addition to the sketches and descriptions, other relevant information was reviewed and synthesized to develop technology-driven design process model. Figure 31 presents an overview of the synthesized results.
**Figure 31.** Overview of the important aspects of the technology-driven design process.

**Decision Making:** The important aspects to consider prior to start a technology-driven design project were addressed by educators (n=3), practitioners (n=4), and students (n=2). For instance, a practitioner mentioned that certain technologies are well suited to industrial designers, and the designers would be eager to work on developing products out of these technologies. Based on this information, considering the technology carefully before deciding to start technology-driven design projects would be beneficial to ensure ID students will be motivated to work on these projects. There were administrative related challenges highlighted by students (n=) (shown ‘Administration’ under ‘Challenge/Concerns of Teaching Technology-driven Approach’). Proffering solutions on how to prevent the addressed challenges would be beneficial to mitigate the struggles the students might encounter.

**Project Kick-off:** The importance of the addressing potential users and forming teams at project kick-off meeting were addressed an educator, a practitioner, and a student. The student mentioned that the emphasis on the importance of end-users in NPD would remind students to
think about users. An educator commented that if collaborating with different disciplines, it would be beneficial to emphasize the role of design NPD so that design students (and design itself) are understood to be important to successful NPD (the challenge is addressed in ‘With Different Disciplines’ under ‘Challenge/Concerns of Teaching Technology-driven Approach’).

**Direction Exploration:** The importance of learning technologies and the impact of technology to society and beyond was addressed by educators (n=9), practitioners (n=8), and students (n=4). Learning the basics and critical role of technology is mentioned as the first stage of direction exploration. Students need to learn and understand the technology including: 1) high-level knowledge of the technology; 2) the scope, breadth and feasibility of the technology; 3) the critical role of technology; 4) competitors with similar technology; and 5) limitations of the technology. Interaction with the technology and materials with tangible objects (if possible) will help students to interpret the meaning of various technologies. Educators and practitioners mentioned that it was helpful to think about the relevance to actual people and the world using the given technology. In the second phase of direction exploration, educators mentioned that correlating the technology with the influence on the user experience was important and finding out where the user actually desires the technology will help to 1) explore potential user groups and 2) know when to use technology and when not to use it. Students also mentioned that interacting with potential users was beneficial to understanding the potential application of the technology in a certain context which helped in generating insights into developing design criteria.

**Idea Development:** Educators (n=2), practitioners (n=6), and students (n=2) mentioned the important aspects to consider and related tools and techniques to use during product idea development phase. Students mentioned that they ideate based on the design criteria, sketching
ideas, building rapid prototypes, and interacting with the potential end-users in this phase. The sketches and prototypes will be iterated and evolved according to the insights given by potential users. Educators and practitioners mentioned that students can use different methods and tools (e.g. mash-up technique, user persona, slice-of life, and Triz) to generate product ideas.

Storytelling and storyboarding were mentioned by educators and practitioners as effective tools not only to present ideas to clients and other team members but also to refine and develop the details of the product ideas while considering of the users’ needs and experience.

**Discussion**

Collecting data from educators, practitioners, students and recent graduates was beneficial to understand the current status of teaching and mentoring regarding technology-driven ID education and the current standpoint of technology-driven design projects in practice from different stakeholders’ perspectives. For instance, while educators and practitioners provided key information sets regarding the technology-driven design process model, students addressed in detail the challenges they experienced from their previous technology-driven design projects.

**Gradual Learning Model:** Several educators mentioned that different student levels are associated with the level of ability to collaborate with technology organizations and to work on technology-driven projects. Students addressed that it would have been beneficial if they could have learned the technology-driven design process prior to working on funded technology-driven design projects. These data imply that a gradual learning model of technology-driven design may benefit students to learn and experience technology-driven projects and better prepare themselves to collaborate with different disciplines. Such a model might include: 1) Technology
to Design Process course, 2) Technology to Design Studio, and 3) Advanced Technology to
Design Studio. The purposes of the Technology to Design Process course would be 1) to
understand the importance of technology in design and 2) to learn and practice the technology-
driven design process. Technology which is highly applicable to ID (e.g., IoT) needs to be
chosen for the course. To focus on learning the technology-driven design process, no other
disciplines would collaborate with ID students during the course. The purposes of Technology to
Design Studio would be 1) to apply the learned process to a real/realistic project and 2) to learn
collaboration skills. Technologies that are not too difficult to apply to ID would be reviewed and
selected by instructors for the course. To learn collaborative skills with other disciplines, one
discipline, such as Industrial Engineering or Graphic and Interaction Design, could collaborate
with ID students. The purposes of Advanced Technology to Design Studio would be 1) to apply
the learned process to a real project and 2) to learn different New Product Development (NPD)
aspects. Various technology-driven NPDs proposed by technology organizations and engineering
departments would be reviewed and filtered by instructors. There would be more than one
discipline collaborating with ID students. Figure 32 provides an overview of the gradual
technology-driven design learning model.
Figure 32. Overview of gradual learning model.

**Student Motivation:** One of the main challenges mentioned by participants was the motivation to learn technology to apply to product ideas. Most of the technology-driven design projects funded by technology organizations require students to focus on certain technologies, and students struggle to identify interesting product ideas to develop from the technologies. Also, practitioners raised a similar concern as the students; the outcomes of technology-driven projects are not sufficient to be included in an ID student portfolio. The first strategy to give motivation to students to learn the technology-driven design process is to apply technologies that are highly applicable in ID and close to end users. Connecting technology to students’ interests and selecting end users close to the students raises interest in working on technology-driven design projects. There are different types of outcomes from technology-driven design projects depending on different expectations from the funding organizations, timeframe, and scope. Sometimes the outcomes will not be conventional ID projects (e.g. a Product Development Roadmap, direction exploration maps, and idea development maps). It would be beneficial for
instructors, funding organizations, and students to understand the value of the different types of final deliverables and discuss the different types of outcomes before starting the projects.

Students addressed that if the learning outcomes are valuable and applicable to other projects, they are willing to take classes to learn new knowledge. Clearly communicating the learning outcomes would allow students to experience the challenge of the technology-driven design process without losing motivation. Figure 33 synthesizes opportunities to motivated students in NDP projects.

![Figure 33](image)

**Figure 33.** Overview of motivating students for NPD projects.

**Categorization of Technology:** Practitioners mentioned certain technologies are well suited to ID and some technologies are more suitable for graphic and interaction design. Careful consideration of technologies was mentioned and categorized as follow: 1) original or applied technology, 2) tangible/intangible technology, 3) close/not close to end users, and 4) which would best motivate ID students for the course. The contemplation of the technology categorization prior to starting technology-driven design projects will benefit instructors to understand which disciplines that ID department to collaborate with for certain technology-driven design projects. Synthesized from the data, Figure 34 presents different aspects to consider when categorizing technology for technology-driven design projects.
Technology-Driven Design Process Model: The data from the surveys and interviews were synthesized to as the ‘important aspects of the technology-driven design process’ in Figure 31; synthesized data from syllabi and activities review are presented in ‘the technology-driven design related activities in the ID current education’ in Figure 24. The models were synthesized to develop the Technology-Driven Design Process Model that can be applied to the front end of the discontinuous NPD process model (Veryzer Jr., 1998) as shown in Figure 35. The tools and methods identified from a previous study (B. Kim & Joines, 2019) can be reviewed and utilized in the different phases of this Technology-Driven Design Process Model.
Conclusion

The purpose of this study is to answer the research question, “How are design students and recent graduates currently educated to contribute their design ability to the technology-driven NPD process?” Using a grounded theory approach, data was collected from ID educators, practitioners, current students, and recent graduates via surveys and semi-structured interviews to answer the main question. Textual analysis was used to synthesize the collected data.

Synthesizing both primary and secondary source data led to the development of seven themes, including: 1) The Importance of Technology in the Design Process, 2) Student Readiness: Technology-Driven Approach Application in Design Education, 3) The Ideal Pedagogical Approach, 4) Experience of Technology-Driven Projects, 5) Tips for the Technology-Driven Design Process, 6) Challenges/Concerns of the Teaching Technology-
Driven Approach, and 7) The Technology-Driven Design Process Model. Four different topics (the gradual learning model, student motivation, categorization of technology, and the technology-driven process model) were discussed to suggest ways to guide teaching and mentoring of ID students and novice designers in a technology-driven context.
CHAPTER 6

THE ROLE OF DESIGN IN THE 4TH INDUSTRIAL REVOLUTION. CASE STUDIES OF DESIGNER’S ROLE IN TECHNOLOGY-DRIVEN ORGANIZATIONS

Chapter 6 is formatted as a manuscript for the submission to The Design Journal.

Title: The Role of Design in the 4th Industrial Revolution. Case Studies of Designer’s Role in Technology-Driven Organizations

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Abstract: This paper presents part of an extensive study that develops design processes, methods, and tools that will help in developing new products in a technology-driven context. This research explores the designer’s role in contemporary technology-driven organizations (TDOs) and how the design process, methods, and tools have been utilized in technology-driven new product development. Case studies were conducted in two TDOs to understand and investigate the role of designers in TDOs in a real-world context. Primary and secondary data were collected and synthesized. The results of the case studies were are presented in this paper including: 1) the role of designers in TDOs; 2) methods for increasing the contribution of design to these organizations; 3) designers’ challenges while working for the TDOs; 4) methods and tools for technology-driven design projects; and 5) the future role of design in the 4th industrial revolution. The results of this study will help update design educational content to enable design students to make the most of their contributions as designers in this contemporary industry.

Introduction

Historically, Industrial Revolutions prompted by technological breakthroughs have
altered people’s way of living (Schwab, 2016). It is vital for companies to simultaneously perceive these changes and adapt them to achieve innovation (Pedler & Aspinwall, 1999). The role of design in new product development (NPD) has evolved with each revolution (Cooper et al., 2017; Heskett, 2001).

The 1st Industrial Revolution (1780s) involved the transitioning from “muscle power to mechanical power” (Schwab, 2016). The technological evolution that inspired the use of steam-powered machines enabled people to concurrently manufacture multiple products. During the 1st Industrial Revolution, over-decorated styling of goods was negatively received by the public (“The Origins and Impact of the Industrial Revolution,” n.d.). The role of design in the 1st revolution was to define and design aesthetically pleasant products based upon the evolved way of producing goods. For instance, Owen Jones illustrated 27 propositions on what makes good design (Heskett, 1980).

The 2nd Industrial Revolution (1870s) was centered around the switch from steam to electric power. This enabled companies to produce massive amounts of identical goods (Schwab, 2016). Since many goods were mass-produced, the need for a variety of aesthetically pleasing products became common (King & Chang, 2015). To respond to this rising aesthetic needs of consumers, designers began to play a crucial role in the mass production of decorated products, in addition to producing functional and usable products (Heskett, 2001). As companies began to differentiate their products to compete with similar products of identical manufacturing and technological processes, the constant changes in appearance were necessary to stimulate the market (Heskett, 2001). For instance, in 1924, General Motors (GM) diversified their car models by adopting different stylings while using common platforms to attract customers with less investment (Heskett, 2001).
The 3rd Industrial Revolution (1960s) is defined as “a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres” (Schwab, 2016, page 2). During the 3rd Industrial Revolution, complex factors needed to be considered before developing products to meet the needs of customers. Diversifying products based predominately on styling became problematic; often highly stylized products failed to meet the customers’ expectations (Heskett, 2001). Companies started to recognize the role of design beyond styling; they began to include design at the strategic level. The need to factor in the desires of potential users in the early phase of the product development process became increasingly important. Consequently, the user-centered design approach became a standard practice. Today, user-centered design has been widely recognized as an important approach in product development (Verganti, 2008).

The 4th Industrial Revolution (current) is defined as “cyber-physical systems” (Klaus, 2016, page 2). However, some aspects of the 4th Industrial Revolution appear to be a prolongation of the 3rd Industrial Revolution. The 4th Industrial Revolution differs from the 3rd Industrial Revolution in three ways: 1) velocity, 2) scope, and 3) systems impact (Klaus, 2016). The exponential growth of technological innovation in the 4th Industrial Revolution enables 1) people to work and consume goods and information remotely and globally; 2) companies to open new markets for rapid economic growth; and 3) conventional production, management, and governance systems to transform into innovative methods (Klaus, 2016). In the 4th Industrial Revolution, new and innovative technologies applicable to products and services are emerging rapidly. Also, as advanced and smart products and services are provided to end-users, their needs are constantly changing. While the 4th Industrial Evolution emerged a while ago, there are few studies documenting the role of design in the 4th Industrial Evolution.

Companies follow different approaches along the spectrum from technology-driven to
market-driven approaches (Ettlie & Subramaniam, 2004). A technology company’s focus is on technology development; they use the developed technology to develop new products (Hao & Song, 2016). One report illustrated that about 30% of companies in the UK depend on technologies when developing new products (Cooper et al., 2017). As the importance of design in the NPD process cannot be overemphasized, the number of designers hired by technology companies has increased (“6 major tech companies have doubled their design hiring goals in the last half-decade”, TechCrunch, n.d.). Despite the increasing need for designers in technology companies, there seems to be little guidance regarding how to maximize their contribution in a technology-driven context.

This research explores the designer’s role in contemporary technology-driven organizations (TDO)s and how these designs have contributed to TDOs. This study was conducted to answer the following questions: 1) how has the designer’s role changed in contemporary TDOs? And 2) how have the design methods and tools been utilized in modern TDOs?

**Research Design Overview**

An inductive, grounded theory approach was used for this study. This study began with broad and high-level questions, collected data under questions, and presents the collected data to have a better understanding of the imposed questions (Bryant & Charmaz, 2007).

A case study, a social science research approach, was adopted to understand and investigate the phenomenon in a real-world context (Yin, 2003; Zainal, 2007). As a research study, a case study follows a general research design process, including how to collect, analyze, and interpret the collected data (Yin, 2003).
A pair of TDOs that 1) predominately develop innovative products and services under a technology-driven context and 2) involves designers taking on certain roles in technology-driven NPD projects, were selected to be included as case studies to answer the research questions.

Case study 1 is of a TDO which will be referred to as Organization A. Organization A was a well-known computer manufacturing company (tangible consumer products) in the ’80s and ’90s. However, it changed its business model and has successfully remained one of the biggest technology companies today. In 2012, Organization A budgeted $100 million for design, and presently, the organization is considered one of the world's largest companies that boast of a large number of designers.

Case study 2 is of a TDO which will be referred to as Organization B. While this organization is relatively smaller than Organization A, this research-oriented organization has researchers from eight different universities as well as a group of about 25 companies. Organization B focuses on energy harvesting, low-power electronics, and sensors utilization in high-value applications and products. The application areas of these technologies include wearable and medical devices. While this organization has not historically worked with designers, two Industrial Design (ID) graduate students were hired in early 2020 to work on technology-driven NPD projects.

**Methods:** Secondary source data published regarding Organizations A and B (such as interview data describing the designer’s role working for the identified organizations, publications, and news articles) were collected and reviewed to understand the overall role of designers in TDOs.

To collect primary source data, semi-structured interviews (see Appendix E) with the designers, project managers (or higher), and engineers working with designers in the
Organizations A and B were conducted to understand the design process, methods, and tools being utilized in contemporary TDOs. The study plan was reviewed and approved by the Institutional Review Board (IRB) at North Carolina State University (see Appendix D).

Data Collection/Synthesis: The secondary source data for Organization A includes: 1) the organization information from the company webpage and 2) two interviews available online — one about a software designer and one about general manager working for Organization A. The secondary source data for Organization B includes organization and related technology information.

The primary source datasets are from 5 interviews: 1) a visual designer and an ID Program Lead at Organization A and 2) two ID students and a project manager at Organization B.

The collected primary and secondary data were synthesized using textual analysis to answer the research questions (Bryman, 2012; Charmaz, 2006; Kvale & Brinkmann, 2009).

Microsoft Word and Post-It™ notes were used for thematic analysis. After the thematic analysis, the coded data, themes, and categories were reviewed by a researcher 1) to consider whether the coded data and themes form a coherent pattern and 2) to determine whether the themes accurately reflect the meanings in the data set (Braun & Clarke, 2006).

Results

The Role of Designer in the TDOs:

Taking the traditional role of design: The value of the traditional role of design in the organization was highlighted. First, products that were a direct result of their technology were identified. Organization A has been working on hardware for computers and server system
infrastructures for several decades, and \(\sim 10\%\) of the organization’s revenue is associated with hardware. One of the industrial designers’ major tasks at Organization A is to design infrastructures components, including machine cases and detail elements, with which end-users physically interact. ID students A and B working for Organization B mentioned that one of their primary roles entailed assembling the technologies into aesthetically pleasing and functional prototypes. Student A’s main job was to research potential users and explore which design aspects needed to be incorporated with the technology.

*Collaborating with engineers to integrate technologies into product design:* Industrial designers at Organization A work jointly with engineers, including mechanical and thermodynamic engineers, to design infrastructures to minimize the noise coming from servers and to maximize the airflow of the cooling system. Since the cost of one machine runs into millions of dollars, the infrastructure needs to be designed exquisitely. If the case is completely opened for better airflow, the noise level will increase. Conversely, if the case is wrapped with a noise-canceling material, airflow will be impeded. The industrial designer’s role is balancing those needs in addition to optimizing the cost of manufacturing. The ID students working for Organization B commented that they jointly worked with electronic and textile engineers throughout the technology-driven design projects.

*Developing early product concepts driven by technologies:* Another role of Organization A’s industrial designer's is to help develop conceptual products from the technology developed from the organization’s research center. The research center develops bleeding-edge technologies, and the organization explores the potential benefits of these technologies to future customers. Industrial designers at Organization A actively work on concept product development projects with the research center. Organization B’s project manager mentioned that even the
current technology-driven projects that ID students are working on have certain scopes. Therefore, he would like to see advanced product ideas that fulfill the potential needs of users.

*Working as a heterogeneous team:* The importance of a heterogeneous team was highlighted during the interviews. For instance, the general manager of design at Organization A believes that the current industry has passed the era of superstar designers but is now in the era of teams. The challenges of the current and future world is complex, and one discipline cannot singlehandedly solve the entire issue. He firmly believes that intentionally creating a team with a diverse culture and the right multidisciplinary skill sets is the driving force that will play a significant role in ensuring a successful outcome. He stated that having formally trained design professionals in a team is crucial for innovation. The project manager of Organization B mentioned that having a small team of people from different backgrounds contributing to the project and working closely with designers was beneficial in providing comprehensive solutions to various problems.

**Ways to Increase the Contribution of Design to the TDOs:**

*Promoting the value of user-centeredness in NPD to non-designer:* The general manager of design at Organization A highlighted that formally bringing the design culture into Organization A was crucial to having design play an active role in the company. He stated that being a design-centered company, was not necessarily about how designers were organized, but more about how non-designers think about the value of design. Likewise, designers must let other team members, such as engineers and developers who are tasked with putting together the final product, recognize the value of design. If through experience, other members of the team can recognize the need for designers, then team members and designers can become allies. Proving the value of design to other team members is a difficult task. The general manager of
design at Organization A stated that it is important to keep challenging other team members when designers know that the features and solutions are not what users want. It is vital to keep the involvement of design thinking at a tactical level. Also, being transparent about designers’ working progress to other team members is equally important in demonstrating the contribution of design in the project. One of the activities that promoted the value of design in Organization B was exposing the designer’s works in the technology-driven NPD process. The role of ID students in one of the milestone presentations to the researchers at the organization was to highlight the importance of focusing on the needs of users to create a better product. Student B mentioned that during the discussion after the presentation, there was an agreement on the importance of finding users’ needs to discover the value of the technology that the researchers have been working on for years. Some of the researchers pointed out that the researchers have been generating massive data. Still, there were doubts regarding how the data was going to be used and who it was going to serve.

*Improving communication skills in an interdisciplinary team:* In Organization A, designers receive their salary based on their business results and evaluation from their co-workers, including non-designers. Designers are responsible for their outcome, precisely the same way as engineers, product managers, salespeople, and marketing people. The general manager of design at Organization A noted that designers need to develop their communication and leadership skills to make their ideas a part of the product. The importance of communication and understanding the value of designers within a heterogeneous team was also brought up. Student B commented that there are always differences in fields and backgrounds within a team. He added that finding the best method to communicate in a way that not only sounded appealing but was easy for non-designers to understand was crucial early on. The method that he used to
break the stereotype (designers only make products look pretty) is sharing each other’s product development process in the early phase of a project. For instance, at the first meeting, he requested to share the individual’s product development process for other departments in the team. After understanding the differences within these processes, he explained how the user-centered design process works. He highlighted that it was essential to understand the individual team member process, as not everyone was adhering to a strict instruction or guide. He mentioned that while this sharing process seems to happen casually, sometimes it does not happen, and there should be a way to prompt this conversation, either from designers or from top management.

**Challenges faced by Designers Working for the TDOs:**

*Technological terms:* The challenge of not being accustomed to technical terms and acronyms were highlighted by both ID students working for organization B. They indicated that there were too many confusing terms (acronyms), and it was challenging to keep up with conversations, especially during the first few meetings.

*Different technologies integrating into one product:* While understanding the technologies involved in the project was not a big challenge for both ID students working for organization B, the difficulties of understanding how the entire technology came together to form one product was addressed. While different technologies were introduced to the students, understanding how different technologies connected took some time for the students. Student B mentioned that the real challenge was repeatedly having to ask questions. The student feared that asking too many questions might become irritating and, as such, tried to limit the number of questions asked during meetings. Instead, he relied on figuring out the topics (technologies and terminologies) by google searching or from books.
Influence of designers to update technologies: Some limitations in terms of how much influence designers have over technological design decisions were addressed. For instance, while student B (in Organization B) generated various ideas for placing five different circuit boards into one shell, he could see other possibilities to design the product in a more user-friendly way by updating the current technology. However, he also admitted that there are limitations to updating any technology due to budget and time constraints.

User research, technology, and product ideas: The challenge of connecting user research, insights, and product ideas was addressed. Student A (in Organization B) explained that understanding potential users and how the possible user exploration translates into design ideas was challenging. The project manager at Organization B also mentioned that while the user journey map used by student A was a valuable tool for analyzing the emotional response state of potential users, it did not yet have a significant impact on product ideas.

A heavy focus on certain design skillsets: The project manager at Organization B noted that student B had excellent skills in 3D modeling in virtual spaces and design ability for the hardware components. While Student B explored different form factor ideas, Student B also seemed to be having a difficult time innovating beyond his skillsets. Overall, the projects worked great as student A was able to bring in the user’s perspective. The project manager mentioned that more innovation might have been realized if student B had been able to think and explore beyond his comfort zone.

Methods and Tools for Technology Driven Design Projects:

Mind map: Mind maps were used in one of the technology-driven design projects at Organization B to categorically generate and organize ideas about diverse potential users. Student A and the project manager at Organization B pointed out that mind map was helpful in
effectively orientating team members to the best way to work together. The project manager mentioned that mind map helped bring up ideas understructure, generating classifications, and organizing different potential users.

*User persona:* User personas helped the students working for Organization B to understand the detailed profiles of different potential users. The project manager at Organization B mentioned that picking an extreme user persona with a more demanding use case gave the team a good starting point for discussion about various product ideas. The project manager mentioned that Organization B heavily focuses on technology, and each researcher is generally a developer of a particular aspect of a specific technology. Because of the heavy emphasis on technology, potential users were often highly generalized. He also noted that understanding users allowed the ID students (in Organization B) to think through the design applications.

*User journey map:* Organization B’s project manager commented that the user journey map was a valuable tool used to understand the emotional response state of potential users. Because the project manager wanted to follow a real-world use case, a user journey map to explore the prospective users’ everyday life was beneficial to envision the application of the technology in detail. However, the project manager remarked that it did not have as much impact on developing product ideas during the process. Also, he added that it would be great if there were tools or guidance to help make the connection between a user journey map and design decisions.

**Discussion**

**Team Members Who Understand User-Centeredness:** The software designer at Organization A mentioned that even though she was the only visual designer in her team, the
project team consisted of other UX researchers and designers. She further added that the team that she worked with had a respectful stance regarding the value of the users and design. She did not have to prove the value of design to the other team members. Instead, she could focus on what she could contribute to her project team as a designer.

**Different Individual’s Ability within a Team:** The necessity of understanding and utilizing different skillsets that different designers have was addressed during the interview. The project manager of organization B’s technology-driven projects mentioned that the different skills that the two ID students brought were beneficial. For instance, student B had a lot of experience with 3D modeling and hardware. Student A’s background with textiles was a great asset for collaborating design and exploring different fabrics. Design mentoring between designers within the team was addressed. Student B, who has an undergraduate ID background, mentioned that he spent some time guiding the other students about a designer’s way of thinking. As student A’s mechanical and methodical approach to her process might limit the holistic view towards product development, student B mentioned that he had many discussions with student A. Student A mentioned that there was more learned from the conversations she had with student B than from her coursework. This implies that while forming a team with more than two designers with different levels of working experience would require additional time for senior designers, the learning experience for the junior designer can be highly valuable.

**Unintended Consequences of the Application of Technology:** On the one hand, the application of advanced and innovative technologies into products and services can significantly improve the user experience. On the other hand, the application of some advanced technologies can cause challenges that were not anticipated by developers and companies. The application of advanced technologies has recently started being used; it is difficult to envision the user scenario
because there are no previous use cases or scenarios. Also, as more sophisticated and improved products and services are provided to end-users, more delicate and sensitive care will be needed. However, it would be difficult for companies to have enough time to test and foresee every possible positive and negative user scenario before providing products and services, because competitors might apply the same technologies and provide similar products and services earlier than them and become dominant in the market. As the application of technology to products becomes more important in the 4th Industrial Revolution, the need for designers to ideate innovative product ideas that incorporate tangible and intangible technologies will be required. When unforeseen challenges occur after the release of a product, the flexibility and willingness to simultaneously respond to the emerging and unexpected challenges are attitudes designers must imbibe to contribute to the continued success of such products and services.

**Tools for Remote Works:** After the stay at home order due to the COVID-19 pandemic, the technology-driven design projects at Organization B were continued online. Some of the tools used during remote work were identified. As the students have a sewing machine (student A) and a 3D printer (student B) at home, they were able to continue prototyping from home. Student B was able to share the progress on his 3D model virtually while working remotely. Organization B’s project manager mentioned that zoom made it possible to see progress and share information. He was satisfied with the team members on a zoom call, and student B pulled up the 3D model to show the progress using the 3D modeling tool in real-time. Student B mentioned that whenever there was a need to deliberate on ideas between students, they share a Google document. Google Doc enabled them to edit a file in real-time instead of sending files back and forth to each other (via email). There were some limitations associated with working virtually, such as providing feedback on physical prototypes which required turning them around
and would have benefitted from trying them on. For instance, the project manager at Organization B mentioned that while the team would like to try to rapidly prototype based on different people's arm sizes, it could not be sufficiently tested. He noted that that whole project would have moved faster if everybody was still working together in the labs. Student B mentioned that sometimes emails were not an efficient way to ask a straightforward question. While Slack communication is better, the student occasionally did not receive notifications and didn't see the messages right away. Student B noted that WhatsApp is a fast communication tool in terms of being faster, non-formal, and ease of use. Student A also mentioned that with WhatsApp, she was able to quickly connect with student B to make sure that things were getting done. Student B also noted the challenge of using too many communication tools. For instance, he posted questions on Slack, and not everybody used slack. He added that picking one virtual communication network which everyone was expected to use would have improve communication between team members.

**Technology Development and Design Development**: Student B discussed the frustration of a designer’s low impact on technology development. The technology development process and technology-driven NPD process are two separate processes (Keersmaecker et al., 2012). While technology development mainly focuses on developing state of the art technology, technology-driven NPD focuses on developing a new and innovative products. Hence, the front end of the technology-driven NPD process supports the transition from technology development to product development. The change is referred to as “Technology Transfer” (Keersmaecker et al., 2012). While design plays a role in the technology transfer phase, designers could also contribute to technology development by envisioning the next step of currently developed technology and suggest the ideas to technologists and engineers.
The Future Role of Designers in the 4th Industrial Revolution: A visual designer working for Organization A responded that the future designer’s role would include working more on the user interface in the context of the advanced technology, such as Augmented Reality (AR) and Virtual Reality (VR). The designers working for Organization A have already been working on VR and AR-related projects. Student B (in Organization B) pointed out that VR has potential uses regarding different ways to collaborate remotely within a project team. He imagined that the whole team could meet in VR space. The team members could come close to each other, see the 3D models, move around, and even reposition. He mentioned that while some companies are working to realizing this idea, most VR collaboration in the design field is currently limited to space design, such as interior design and architecture. The designers indicated that the projects in Organization A are complex. As such, no single discipline can solve the encountered problem during projects. Hence, interdisciplinary or even transdisciplinary team culture will become a norm in the company. So, designers should learn how to work closely with other disciplines. Organization A’s ID Program Lead mentioned that industrial designer’s future role within Organization A would not be very different from their current role, because of the characteristics of industrial design. The physical design needs to be finalized at the front end of the NPD, and after the design has been documented (e.g., patented) and/or manufactured, there is no room for changes. On the other hand, he sees the software designers’ ability to update the version of their products even after the products have been released to the public. This flexibility for software designers means more involvement throughout the whole process of NPD. Unlike in the 1st and the 2nd Industrial Revolutions, where tangible products were dominantly provided to the end-users, intangible services and products, such as online platforms and apps, are mainstream in the 21st century. For instance, developers and designers can fix bugs in a released
app and have the updated one available to the end-users. The end users do not need to abandon the app and purchase another one; they can simply have their app updated. From this perspective, there is no definite “end” of software products and services, but there is improvement through a “more updated version”. The role of designers and developers in the NPD cycle in the current and upcoming industry would be different from the conventional designers' and developers’ role in the past.

**The Role of Design and Design Education:** Design has since taken the role of increasing the value of products for users, and such products cannot be separated from industry (Heskett, 2001)(Cooper et al., 2017). Hence, as industry changes over time, the role of design in industry needs to be shifted accordingly. If designers are well prepared through their design education to adapt to a new role, they can maximize their contribution to industry. As the importance of the design process has been recognized, designers are not only involved in aesthetics but also expanding their role throughout the entire product development process (Cooper et al., 2017). A considerable amount of effort has been contributed by companies adopting a technology-driven approach. Either they focus heavily on a technology-driven approach or at least partially putting their effort and budget in it (Cooper et al., 2017). However, based on previous studies, there were relatively few documented design curriculums that defines the role of designers in a technology-driven context. Teaching design processes with a technology-driven approach and allowing students to have develop technology-driven design skills may help students understand how to obtain the vital knowledge of the technology that can be transformed into product ideas. This is intended to help design students develop their ability to connect technological know-how to creativity and the potential needs of users. As student B mentioned in this study, some design students have a fear of learning about technology and
as a technology-driven NPD approach could lower decrease students’ fears and anxiety regarding learning new technologies. This should enhance their confidence in interacting with technologists and engineers, which would eventually improve the design student’s communication skills in an interdisciplinary work environment. Design has taken an essential role in increasing the value of products for users (Cooper et al., 2017; Heskett, 2001). As the contemporary industry shifts into the 4th Industrial Revolution, the role of design will be different compared to/in addition to the past role. While the rate of technology change over time shows exponential growth, the rate of human adaptability to technology over time has a gentle linear growth according to Astro Teller's graph (Friedman, 2016). According to the graph, the rate of technological changes finally surpassed human adaptability in 2007. The designers trained using a user-centered design process can contribute to mitigating the gap between technology and human adaptability by designing products and services in a more user-friendly manner. Design education is responsible for teaching students how to develop their design-related skills and knowledge so that students can confidently work as problem-solvers in industry (Goldschmidt & Casakin, 1999). Hence, design education must respond to designers’ changing role in the industry by updating its educational content; thus design students can be ready to maximize their contribution as designers in the industry.

**Conclusion**

Investigating the role of design at Organization A provided a better understanding of the current role of designers in a large TDO that successfully shifted their business from traditional consumer products to software and service-based focus. Investigating the role of design students and their experience working on the technology-driven design projects at Organization B
provided a better understanding of the designer’s role in a medium size TDO.

Synthesizing the collected data led to the development of five topics directly associated with both research questions, 1) how has the designer’s role been changed in contemporary TDOs? and 2) how have the design methods, and tools been utilized in contemporary TDOs? The five topics include: 1) the role of designer in the TDOs, 2) ways to increase the contribution of design to the organizations, 3) challenges as designers working for the TDOs, 4) methods and tools for technology driven design projects, and 5) the future role of design in the 4th industrial revolution. Other topics indirectly associated with the research questions were discussed in this paper. The results of this study will help update design educational content so that design students can be ready to maximize their contributions as designers to contemporary industry.
CHAPTER 7

DESIGN PROCESS, METHOD AND TOOL EVALUATION: TECHNOLOGY TO PRODUCT DESIGN PROCESS (TPDP) FOR INDUSTRIAL DESIGN EDUCATION

Chapter 7 is formatted as a manuscript for the submission to the International Journal of Art and Design Education.

Title: Design Process, Method and Tool Evaluation: Technology to Product Design Process (TPDP) for Industrial Design Education

Authors: Byungsoo Kim, Sharon Joines, and Derek Ham (College of Design, North Carolina State University, Raleigh, NC)

Abstract: While Industrial Design (ID) university students have ample opportunity to learn market and user-centered approaches, ID education seems to lack curriculum that teaches the technology-driven New Product Development (NPD) approach. Since a considerable number of companies focus on technology-driven approaches, educating ID students on a technology-driven approach to developing new products would improve the contribution of design education to the contemporary industry. Based on the results of previous studies, the Technology to Product Design Process (TPDP) and related tools were developed to be used in ID education at the university level. The purpose of this study is to evaluate the use of TPDP and related tools by Industrial Design educators and design practitioners. Semi-structured interviews were conducted to gather feedback about the process and tools. Based on the synthesized results, the design process, methods, and tools for TPDP and related methods and tools were updated. The results of this study will give useful insights to Industrial Design educators. TPDP and related tools can help instructors to teach and guide ID students to become design practitioners who will actively contribute their design skills and creativity to technology organizations.
Introduction

Product and service Innovation is a crucial component of company success (Ali, 1994; Corso & Pellegrini, 2007; Norman & Verganti, 2013; Walsh, 1996). Scholars categorize innovation to develop new products and services into different levels in terms of technological breakthrough, newness, and novelty (Ali, 1994; Garcia, 2002b; Hoyer & MacInnis, 2018; Maarse & Bogers, 2012; Robertson, 1971; Tushman, 1997; E. Yoon, 1985).

Discontinuous innovation is defined as creating original products (e.g., the development from button type cellular phones to touchscreen smart phones) while continuous innovation is defined as reformulating new products (e.g., a tablet PC with e-book reader, a tablet PC with in-cloud data storage, or a tablet PC with front and rear digital video cameras) (Yoon, 1985). Discontinuous and continuous innovation are assessed within the following categories: 1) whether the innovation is from a technological breakthrough or existing technologies (Ali, 1994; Maarse & Bogers, 2012; Tushman, 1997); 2) based on the level of originality (E. Yoon, 1985); and 3) based on customer behavior (Hoyer & MacInnis, 2018).

It is important for companies to pursue continuous innovation in addition to discontinuous innovation to achieve short- and long-term success (Tushman, 1997). As discontinuous products are strongly associated with technological advances (Ali, 1994; Maarse & Bogers, 2012; Tushman, 1997), managers need to find specific uses or markets for a promising technology during a period of rapid technological expansion (Ali, 1994). This approach can be defined as a technology-driven NPD approach, in which the innovation is dependent on technology (“Technology-driven Definition in the Cambridge English Dictionary,” n.d.).

Creating value and new meaning for products that change customer behavior is necessary
to achieve discontinuous innovation in addition to the application of advanced technologies.

Since the core of design’s contribution to NPD is creating valuable products (Cooper et al., 2017; Heskett, 2001), designers are expected to develop new products that are unique and valuable for the customer.

While Industrial Design (ID) university students have numerous opportunities to learn the market and user-centered approaches, previous study results implies that ID education seems to lack curriculum teaching a technology-driven approach (B. Kim, Joines, & Feng, 2020). Since many companies focus on technology-driven NPD approaches (Cooper et al., 2017), teaching ID students this technology-driven approach to developing new products would improve the contribution of ID education to the contemporary industry.

The Technology to Product Design Process (TPDP) and related methods and tools have been developed based on previous studies (B. Kim, Joines, et al., 2020; B. Kim, Liu, & Joines, 2020). The purpose of this study is to evaluate the use of TPDP and related tools by ID educators and practitioners. Based on the synthesized results, the design process, methods, and tools for TPDP were updated. The results of this study will give useful insights to Industrial Design educators that can help instructors to teach and guide ID students to become design practitioners who will actively contribute their creativity to technology organizations.

**Methods**

Expert reviews, including semi-structured interviews, were conducted with ID educators and practitioners. The expert review lasted 90-120 minutes (Zoom video conferencing software was used to host, record, and transcribe the sessions). Initially, the researcher shared computer screen to explain the details of the process, methods, and tools and took notes during the
The Technology to Product Design Process, developed from the previous studies (B. Kim, Joines, et al., 2020; B. Kim, Liu, et al., 2020), was introduced to the participants. The semi-structured interview questions were developed based on the findings of previous studies (B. Kim, Joines, et al., 2020; B. Kim, Liu, et al., 2020; Liedtka, 2017), including: 1) empathic understanding of user needs and context, 2) the formation of heterogeneous teams, 3) problem definition/opportunities first and then considering the new application of technology, 4) creation of multiple solutions, 5) structured and facilitated process, 6) enhancement of student motivation, 5) guidance of technology application product idea, 6) thinking about different aspects of technology, 7) consideration beyond users, 8) guidance to create satisfying outcomes, and 9) class/project administration. Textual analysis was used to synthesize the transcribed data from the interviews (Bryman, 2012; Charmaz, 2006; Kvale & Brinkmann, 2009). The study plan was reviewed and approved by the Institutional Review Board (IRB) at North Carolina State University (see Appendix F). See appendix G to review the interview questions.

The participants needed to have enough ID working/teaching experience so that the researcher could collect valid data. The inclusion criteria were: 1) designers with at least three years of working experience in technology companies or involved in technology-driven new product development projects; or 2) design educators with at least three years of teaching experience, either in a project-based learning environment or in lecture-type classes. The data from 11 participants who participated in the interviews was synthesized to update the Technology to Product Design Process (TPDP) and related methods and tools. A summary of participant demographics is shown in Table 6.
Table 6.  
*Demographics of participants (Ps).*

<table>
<thead>
<tr>
<th></th>
<th>Teach (taught) Undergraduate Courses</th>
<th>Teach (taught) Undergraduate Courses and Graduate Courses</th>
<th>Industry (field)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID educators</td>
<td>P1, P4, P6</td>
<td>P2, P5, P8, P9</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Design practitioners | N/A                                  | N/A                                                     | • ID education background and currently in UI, UX design department: P7, P10  
• ID education background and currently project manager: P3 |

TPDP was developed based on feedback from 58 design practitioners, educators, and ID students who had experience with technology-driven projects (B. Kim, Joines, et al., 2020; B. Kim, Liu, et al., 2020); the related methods and tools were developed/refined based on close observation of how two ID students and a project manager worked on two technology-driven projects (Organization B in Kim, Liu, et al., 2020). Table 7 shows the characteristics of technologies that the previous participants experienced in technology-driven NPD projects. The categorization of technologies are drawn from previously defined taxonomies (Crawford, n.d.) and some have been updated from the previous study (B. Kim, Joines, et al., 2020).
Table 7.
*Characteristics of technologies that TPDP and related methods and tools development participants experienced in technology-driven NPD projects.*

<table>
<thead>
<tr>
<th>Technology Sector Categories (Crawford, n.d.)</th>
<th>Agriculture</th>
<th>Medicine</th>
<th>Manufacturing</th>
<th>Energy</th>
<th>Transportation</th>
<th>Information</th>
<th>Entertainment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updated Categorization (B. Kim, Joines, et al., 2020)</td>
<td>Hardware TPDP¹</td>
<td>TPDP Methods</td>
<td>TPDP</td>
<td>TPDP Tools²</td>
<td>TPDP Tools²</td>
<td>TPDP</td>
<td></td>
</tr>
</tbody>
</table>

¹TPDP is based on 58 participants
²Methods/tools are based on observation of 3 participants

**Results**

The feedback and suggestions about TPDP and eight related methods and tools from the eleven interviewees were synthesized and are presented in this paper. The synthesized results are presented in the following order: 1) TPDP, 2) Technology and Design Checklist, 3) Simplified Visualization of Technology, 4) Contextualization of the Tech and Beyond, 5) Potential User Exploration, 6) Mash-up Users and Tech, 7) Prioritization of Potential Users, 8) Design Criteria and Insights, and 9) Slice of Life. TPDP and related methods and tools were updated based on the given feedback and suggestions (see “Chapter 8: Conclusion”).

**Technology to Product Design Process:**

An overview of TPDP is presented in this section with the context of an ID studio (in a University). The first step is decision-making. Based on the researcher’s previous studies, there
are different aspects to consider before collaborating on a technology-driven design project with a technology company who wants to work with an ID program. These aspects include: 1) application of technology to ID, 2) collaboration opportunities, and 3) administration of the class. A checklist was developed according to the three aspects to guide the discussions of ID instructors with technology companies.

The second step is project kickoff. During the previous studies, design educators mentioned that students tend to come up with product ideas as soon as they hear the features of the technology without first exploring the technology. Emphasizing user-centeredness by delivering an introductory lecture on who needs the technology at the front end of the technology-driven NPD project will be beneficial when formulating an interdisciplinary team. When forming project teams, many design instructors in the previous studies noted that it is important to have team members with educational backgrounds (e.g. Graphic Design, ID, MBA/Marketing, Textile, Industrial Engineering, Mechanical Engineering) so that students can learn different skillsets and points of view from each other. In the case of interdisciplinary team projects, the educators from the previous studies noted that ID students need to be reminded of what they can do compared to other disciplines in order to promote the value of design within the team.

The third step is direction exploration. Students will learn about the technology and related topics through different methods and tools, including: 1) simplified visualization of technology, 2) contextualization of the tech and beyond, 3) interaction with the technology/materials, 4) competitor analysis, and/or 5) workshops. Based on their understanding of the technology and its impact, students will explore potential users of the technology utilizing different methods and tools, including: 1) mind map for potential user exploration, 2) mash-up
The fourth step is idea development. Students will engage with the target potential users to identify occasions where users would benefit from the technology. At this stage, students will develop design criteria, gain insights from potential users, begin ideating new products, and build rapid prototypes. After developing these prototypes, students will create user scenarios with compelling storytelling. The overview of the TPDP process introduced to the experts is shown in Figure 36.

Figure 36. Technology to Product Design Process overview.

**Application of technology to ID**: Participant 8 (P8) noted that a given stage of technology applied within a different period of time, such as within the next 1-2 years versus 10-20 years from now, will drive different outcomes.

**User-centered direction**: P9 pointed out the importance of considering different
stakeholders in addition to potential end users. P1 addressed that knowing how to divide up responsibilities and coming back to an empathetic understanding of users in interdisciplinary student teams is challenging.

*Learning technology:* P3 addressed that to be able to have valuable insights, designers need to spend a similar amount of time learning technology as they spend on user research. While P10 suggested that students can capture sparkling product ideas while learning technology, instructors need to encourage students to keep exploring technology and potential users that will benefit to generate product ideas benefitting potential users.

*Use case exploration:* P3 noted that both design students and the technology company funding the project need to be more flexible and willing to conduct multiple sets of use case exploration. P6 addressed the importance of understanding clients’ needs in addition to those of potential users so that the value to the client are addressed throughout the design process.

*Find valuable application of technology:* P2 commented that students should be careful not to define a problem based on a superficial understanding of potential users and that, when investigating a potential user, it is important to discover the hidden needs of users and stakeholders in a variety of circumstances. P7 mentioned that more insights are gained when observing potential users’ actions compared to conducting interviews.

*Storytelling:* P3 noted that illustrating the benefits to potential users is crucial for technologists to pitch the importance of developing the technology to their funding sources. For instance, persuasive storytelling about how the technology will significantly benefit potential end users will increase the likelihood of receiving funding from upper management of big companies or funding foundations (e.g., the National Science Foundation) and allow them to develop the next stage of the technology or product.
Tool/Method 1 (Technology to Design Checklist):

The researcher’s previous studies imply that the Technology to Design Checklist (shown in Figure 37) will help an ID program decide whether to collaborate with a given technology company proposing to work with ID students. The questions developed under “Technology Suitable to ID” will help ID instructors evaluate the suitability of the technology to development in ID studios. The questions under “Collaboration opportunities with other disciplines” are intended to help design educators understand the potential for collaborating with different departments within or outside of design to develop products from the proposed technology. The questions under “Administration” will help instructors consider how to better manage such a sponsored studio project, including: 1) time management, 2) project scope and outcome, 3) student management, and 4) resources.

<table>
<thead>
<tr>
<th>Technology Suitability to ID</th>
<th>Closeness to End-Users</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1. Does this technology directly interact with end users (i.e. a chair directly interacts with end-users. On the other hand, semiconductor is not directly related to end-users)? Also, is this technology applicable to everyday life? If no, consider which aspects ID students can contribute to explore product ideas starting from this technology.</td>
</tr>
<tr>
<td></td>
<td>Applicability to Product Ideas</td>
</tr>
<tr>
<td></td>
<td>Q2. Can you envision that ID students can exploring new product ideas? If no, reconsider working with ID student to develop new products starting from the technology, unless the project goal is to understand the level of the applicability to product ideas from the given technology (note that the level of applicability to product idea can be close to zero).</td>
</tr>
<tr>
<td></td>
<td>Physical Elements</td>
</tr>
<tr>
<td></td>
<td>Q3. Does the application of technology associate with tangible aspects? If no, consider collaboration opportunities with other departments.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collaboration opportunities with other disciplines</th>
<th>Graphic/Interaction Design/Computer science</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q4. Does the application of technology related to data visualization or software development?</td>
</tr>
<tr>
<td></td>
<td>MBA/Business/Marketing</td>
</tr>
<tr>
<td></td>
<td>Q5. Does the scope of the project or learning outcome include product launching strategies, product roadmap, and cost benefit analysis?</td>
</tr>
<tr>
<td></td>
<td>Textile, Industrial Engineering, Mechanical Engineering</td>
</tr>
<tr>
<td></td>
<td>Q6. Does the technology requires to understand specific sensor, materials, or engineering related knowledge?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Administration</th>
<th>Time Management</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Q7. How long is the given amount of time for the project?</td>
</tr>
<tr>
<td></td>
<td>Project Scope and Outcome</td>
</tr>
<tr>
<td></td>
<td>Q8. What would be the anticipated project scope/outcome (i.e. direction exploration, idea development, and product development)?</td>
</tr>
<tr>
<td></td>
<td>Student Management</td>
</tr>
<tr>
<td></td>
<td>Q9. What is the level of students who will work on the project?</td>
</tr>
<tr>
<td></td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td>Q11. How much of the materials will be needed to experience the technology for the project?</td>
</tr>
<tr>
<td></td>
<td>Q12. Are there available individuals to invite as external critics from professional designers and technologists?</td>
</tr>
<tr>
<td></td>
<td>Q13. If different level of students (i.e. undergraduate and graduate students) will work together, how to form teams and guide students accordingly?</td>
</tr>
</tbody>
</table>

Figure 37. Tool/Method 1: Technology to Design Checklist.

Technology suitability to ID: P1 commented that if there is no growth for the student, there is also no design education value of the project. Regarding the physical aspect of the technology, P1 and P3 addressed that while tangible aspects are valuable for an ID program,
there is an increasing number of students who graduate from ID programs and only focus on learning software products and service, such as UX and UI. Hence, how to realize products and services from the technology, whether physical or non-physical, is an important aspect to consider. P6 noted that while some technologies focus heavily on making a profit for technology companies, some might be more related to non-profit organizations, such as technology contributing to social innovation. P7, P10, and P11 commented that the questions regarding closeness to end users or applicability to product ideas would be difficult for technology companies to clearly answer when initially engaging with ID programs to propose a project. The prepared questions (see Figure 37) will help ID faculty members who have been asked to collaborate with technology companies. With these questions, faculty members can explore various options to guide students through developing a specific technology.

Collaboration opportunities with other disciplines: P4 pointed out that conflicts between ID students and students from different disciplines often arise when the division of labor is not clear at the front end of the project. The questions in this category (see Figure 37) will guide instructors in discussions and labor division for different disciplines. P8 mentioned that she could not recall finding opportunities for collaboration with the Computer Science program. In the past, she had collaborated with Electronic and Computer Engineering.

Administration: P3 noted that considering the client’s background is a crucial aspect when presenting the outcomes of project (for instance, if the CEO of a company used to had a finance background, creating a Gantt chart to put the plan together in a way he or she understands would be beneficial). P8 mentioned that if filing a patent is one of the main objectives of the project, it is important to have information on which terminologies and in which repositories or search engines should be used to search. Since ID students have limited
experience with this type of information, the information can be directed by technology companies.

*The role of the instructor:* P2 commented that since students have no or few experiences in technology-driven design projects, they often wonder whether ID is a necessary part of developing products for a technology-driven project. P3 noted that in the contemporary industry, ID combines various pieces of knowledge to make a successful product; hence, it is essential that students recognize the important role of ID in a technology-driven project.

**Tool/Method 2 (Simplified Visualization of Technology):**

Under the context of a funded technology-driven studio project, ID students typically learn about the relevant technologies as follows. First, the technologists or engineers come to one of the classes and give a lecture about the technologies — providing technology demo materials if applicable. As understanding the technology is crucial in technology-driven design projects, the instructors need to recognize the students’ level of understanding of the technology. One of the design educators in the previous study mentioned that it was very helpful for him to ask students to sketch their understanding of certain processes. Similarly asking students to visualize the technology based on their current understanding would allow instructors to assess the students’ level of understanding of the technology. Before creating the visualization, students need to digest what they have learned. The Simplified Visualization of Technology method developed from the previous studies was introduced to the experts (see Figure 38) for their review.
More detailed guidance: P8 and P10 suggested that it would be nice to have an intermediate process to guide students in visualizing the technology, such as providing them with a list of which aspects/characteristics of the technology should be visualized. In addition to the visualization of technology, P4 suggested to take a test to objectively understand the students’ level of technology-knowledge.

Importance of deep understanding of the technology: P3 noted that while visualizing technology sounds like an effective way to digest the technology from the student’s end, it is important for students not to oversimplify the key characteristics of the technology. Based on P2’s previous technology-driven design project experience, he observed that students who dive
deeper into understanding the technology are more likely to come up with unique and unexpected results. The teams that hadn't put effort into understanding the technology ended up with predictably subpar deliverables.

*The role of the instructor:* P4 and P10 stated that it is important to inform students clearly about the purpose of this activity and to help them understand the key attributes of the technology, not to simply create visualizations. Otherwise, students are more likely to spend too much time creating pretty visualizations. P4 expressed concern that when students are asked to visualize what they understand about the technology, they will likely visualize only those parts they already understand, without putting in the effort to understand the technology’s key attributes thus fleshing out their understanding. P3 mentioned that the role of the instructor in teaching the technology should be to pose interesting questions about the technology that will be essential to understand in order to connect potential users and develop product ideas.

**Tool/Method 3 (Contextualization of the Technology and Beyond):**

The researcher’s previous study addressed the importance of studying the context of technology. Students can utilize the template shown below to contextualize the technology, including to consider 1) its advantages and limitations, 2) the unintended consequences and impact of the technology, and 3) the technology and related politics. The Contextualization of the Tech and Beyond matrix developed from the previous studies was introduced to the experts (see Figure 39) for their review.


**Figure 39.** Tool/Method 3: Contextualization of the Technology and Beyond.

**Advantages and limitations:** P7 commented that when technologists or engineers develop a particular technology, there must be an initial reason (e.g., developing motor technology that makes less noise and is more powerful than its competitors) and purpose (e.g., the motor technology will improve the performance of outdoor gardening tools) in their mind of how the technology will impact future products and society. The purpose and hypotheses need to be clearly explained to students so that they can explore these impacts based on the initial reason and purpose. P3 and P11 suggested that it would be beneficial to provide a more granular guide for classifying and analyzing certain advantages and disadvantages according to the characteristics of the technology.

**Unintended consequences/impact; technology and politics:** P11 noted that the impact of a technology differs depending on context, such as whether it is applied in daily life at home or in an office environment for professional work, and suggested that a guide within the tool would help students to think about these different contexts. P6 observed that the impact of the
technology could be more specific, such as addressing social and environmental impacts. P5 pointed out that the technology and ethics should also be considered (e.g. who will be given access/ alienated to the technology and the impact of technology to human right).

Additional guidance to summarize information and identify opportunities: After this activity, P6 stated that there should be more guidance for generating the technology characteristics lists that are used for the next activity, the mash-up technique for users and technology. P6 also suggested that it would be beneficial to discuss the opportunities presented by the technology based on the understanding of the given technology and beyond. P3, P5, and P10 suggested using different tools to synthesize the gathered information from this template, including 1) a SWOT analysis and 2) a checklist or matrix template to evaluate the technology within certain parameters, such as simple to complex, novice to expert users, and the level of control allowed for users.

The role of the instructor: P1 and P3 mentioned that finding a good resource to help students consider the unintended consequences and the impact of the technology on society would be an important role of the instructor, as it would be difficult for students to find this information and make connections by themselves.

Tool/Method 4 (Potential User Exploration):

After understanding the technology and the context of its application, students will start to explore potential users who will benefit from the technology. Since mind maps were successfully used in the previous study to explore potential user groups in a categorized way (B. Kim, Liu, et al., 2020), using a mind map for potential user exploration was introduced to the experts (see Figure 40).
Figure 40. Tool/Method 4: Potential User Exploration.

*Emphasis of the purpose of the mind map:* P4 mentioned that it is important to inform students about the main purpose of this activity: to explore potential user groups who will benefit from the technology. Otherwise, students will be more likely to focus only on generating potential users for whom the technology is not necessarily relevant.

*The role of the instructor:* P3 commented that it would be beneficial for students to receive guidance regarding sources to generate ideas about potential users, either through secondary research online or through direct interaction with people.

**Tool/Method 5 (Mash-up Users and Technology):**

Utilizing the Mash-up Technique (“Ideation Method: Mash-Up – IDEO U,” n.d.) to explore potential users who will be benefitted by the technology was examined in the previous study (B. Kim, Joines, et al., 2020). The steps of this activity are as follows: 1) list potential user groups and characteristics identified from the previous activity using mind maps; 2) list technology characteristics identified from the previous activities, “Simplified Visualization” and “Contextualization of the Tech and Beyond”; and 3) match potential user groups and technology characteristics from each list. The method of utilizing the Mash-up Technique to explore users was introduced to the experts (Figure 41).
Importance of exploring creativity: P4 explained that the human brain commonly thinks in one dimension, and when information from another dimension comes in, new and creative ideas can emerge. P4 also noted that what is currently lacking in design education is allowing students to try these creative activities. While some irrational ideas may be generated, and most of them will not be acted upon, it is still important to explore and consider these ideas through this activity.

Collaboration with other disciplines: P2 commented that if only ID students participate in this activity, some characteristics of the technology may be missed. P2 suggested that if design and engineering students engage in this activity together, they can learn from each other and produce better results.

The role of the instructor: P9 mentioned that matching potential user groups’ characteristics to a technology characteristic might be difficult for some students; therefore, instructors should guide students to think about unknown products or services that have not yet
been identified in the mind map.

**Tool/Method 6 (Prioritization of Potential Users):**

When ID students present potential users to the technology company that is sponsoring the project, the company wants to understand the reasons for which these potential users were chosen to move forward, and these reasons need to be closely associated with the given technology (B. Kim, Liu, et al., 2020). This template will help students prioritize potential user groups based on the reasons identified through the previous activities (e.g. “Contextualization of the Technology and Beyond,” “Potential User Exploration,” and “Mash-up Users and Technology”). The Prioritization of Potential Users template developed from the previous studies was introduced to the experts (see Figure 42).

![Figure 42. Tool/Method 6: Prioritization of Potential Users.](image)

**Consideration of reasons potential users have been identified:** P3 mentioned that some of the reasons behind why a student chooses to explore a certain potential user group further may be technology-based or not. For example, the reason could be simply because a certain market is easier for the company to sell its potential products to.
Consideration of different contexts: P5 noted that the five potential user groups listed in this template need to include a context in which the technology can give the most benefits to the users.

Relation mapping with previous activities: P6 and P9 suggested that it would be beneficial for students to map the relationship between the information in “Prioritization of Potential Users” and “Contextualization of the Technology and Beyond.” P6 noted that as the technology will have different impacts on different demographics based on social and environmental factors, mapping out the relationship between the two tools would help students to think about potential users using different layers.

Tool/Method 7 (Design Criteria and Insights):

One of the primary difficulties ID students face is how to analyze the targeted potential users and derive design ideas from the analyzed results (B. Kim, Liu, et al., 2020). By having user profiles, user sequences (simplified user journaling maps), design criteria, and insights on a single page, this template will help students to identify connections among the three tools. The Design Criteria and Insights template developed from the previous studies was introduced to the experts (see Figure 43).
Consideration of different contexts for user profile: P4, P6, and P8 noted that when summarizing potential users, it is important to consider different contexts in which the potential user group can benefit from the technology. The user profile should be created based on the context and should address how the technology will benefit the potential users instead of including unnecessary information, such as name and birthday.

Consideration of technology-heavy user profile: P10 expressed concern that depending on the selected potential user group, the technology may be used very little. P10 suggested developing the user profiles in two different tracks: expert-level usage of the technology and use of the technology in everyday life. For instance, the first potential user might depend heavily on the technology for work while the second potential user might use the technology at home.

Tool/Method 8 (Slice of Life):

The Slice of Life method presented by Gardien and Kyffin (2009) was simplified and developed as a template and then introduced to the experts (see Figure 44).
Figure 44. Tool/Method 8: Slice of Life.

Utilization of this template for final presentation: P9 positively commented on this tool in terms of presentation to clients. As this template presents a snapshot of the most important stories from “Design Criteria and Insights,” it would be more impactful to present these findings to the clients.

Inclusion of ideation section in the template: P6 suggested that as students start to think about the details of the product design using this tool, it would be helpful to include a section in the tool to capture those ideas.

Collaboration with other disciplines: P6 noted that in the case of a multidisciplinary project, it is important to consider at least parts of activities to which other disciplines contribute, rather than only the efforts to complete the tool by design students. As students in different majors have different areas of expertise, P6 suggested that the template could provide a way for those in other disciplines to contribute their specialties to product idea development.

The role of the instructor: P10 commented that the role of the instructor at this stage should be to guide students’ understanding from the perspective of the targeted users and to provide opportunities for the students to engage with the targeted users.
Discussion

Interdisciplinary Contribution to Project: P1 and P9 observed that ID students generally spend more time on projects than students from other disciplines because they tend to be more project-oriented than grade-oriented. In order to find unique design opportunities, repeated trial and error is inevitable. In contrast, both P1 and P9 noted that many engineering students hesitate to go through several iterations because their goal is to earn good grades. This implies the necessity of reconsidering a grade-oriented system in collaboration design projects.

Empathy for Potential Users in Interdisciplinary Project: P1 noted that dividing responsibilities among different disciplines and coming back to conduct user research will be challenging for interdisciplinary teams. P1 and P4 suggested that having ID students conduct the primary research and then share their experience with other team members might be a feasible approach. For instance, if the user research was on smartphone usage, ID students can share a video that addresses some of the critical challenges (e.g., while cooking, users tried to click a button on their smartphone with their elbow because their hands were wet). ID students can pause the video right before the key moment and have team members discuss what the user’s next behavior will be to raise empathy for users.

Implementation of Diversity in Design Decisions: P7 addressed that although there is increasing awareness in terms of the value of diversity within a team, it is difficult to answer the question of whether diversity is currently reflected in the decision-making process. In order for diverse disciplines to be included in designing products, a well-structured and facilitated process will be important.

Project Outcome vs. Learning Experience: P2 expressed a frustration that in the case of funded projects, often the focus is placed on the outcome of the project, not on the students’
learning experience.

**Documentation of Design Process:** P3 mentioned the importance of documentation of design process to collaboration with other disciplines and noted that for other disciplines, the design process seems like pulling ideas out of thin air, and therefore they do not put much credence in the ideas. If designers rigorously document their process and explain their reasons (i.e., how they developed the ideas from A to B to C, rather than presenting C out of nowhere), other disciplines may accept the ideas more readily.

**Designers Who Empathize with Potential Users:** Based on P10’s previous experience working on funded projects with students, successful project outcomes are strongly associated with whether the target potential users’ characteristics are matched with those of the students working on the project, as the students then have empathy for the target users. P7, P10, and P11 commented that in industry-academia cooperation projects, in most cases, companies seek fresh ideas from students. In these aspects, matching technology-driven design projects with designer students who have similar characteristics to those of the potential user group (e.g., age group and interests) could increase opportunities to find valuable project ideas and further benefit users through the technology.

**Conclusion**

The developed Technology to Product Design Process (TPDP) and related methods and tools were reviewed by ID educators and practitioners. The experts’ feedback was synthesized to update the design process, methods, and tools (see Appendix). Their insights in terms of how to teach and guide ID students in technology-driven design projects have been discussed in the discussion section. The results of this study provide insights to ID educators in order to assist
instructors in teaching and guiding ID students to become design practitioners who can actively contribute their creativity to technology organizations.
CHAPTER 8
CONCLUSIONS

Summary of the Three Studies

The results of Study 1 answered the research question, “How are design students and recent graduates currently educated to contribute their design ability to the technology-driven new product development (NPD) process?” with synthesized results from both primary (semi-structured interview and surveys) and secondary source data (publicly available information online), including: 1) The Importance of Technology in the Design Process, 2) Student Readiness: Technology-Driven Approach Application in Design Education, 3) The Ideal Pedagogical Approach, 4) Experience of Technology-Driven Projects, 5) Tips for the Technology-Driven Design Process Model, and 7) The Technology-Driven Design Process Model.

The results of Study 2 answered the research questions, 1) “how has the designer’s role changed in contemporary TDOs?” And 2) “how have the design methods and tools been utilized in modern TDOs?” by investigating the role of design at two TDOs. Synthesized results from primary source data (semi-structured interviews) led to the development of five topics directly associated with both research questions. The five topics include: 1) the role of designer in the TDOs; 2) ways to increase the contribution of design to the organizations; 3) challenges as designers working for the TDOs; 4) methods and tools for technology driven design projects; and 5) the future role of design in the 4th industrial revolution.

The results of Study 3 answered the research questions, “How to improve TPDP to be effectively taught to design students in educational setting?” The developed Technology to Product Design Process (TPDP) and related methods and tools were reviewed by ID educators
and practitioners. The experts’ feedback was synthesized to update the design process, methods, and tools.

**Updated TPDP and Related Tools**

All participants in Study 3 positively commented the TPDP presented to them; there were no direct comments to update the process. Since the indirect comments and suggestions given for TPDP were strongly associated with the related methods and tools, the methods and tools were updated accordingly. The experts’ feedback in Study 3 was synthesized to update the methods and tools related to TPDP that were developed from Study 1 and 2.

The main technology, Thermoelectric generator (TEG) (energy harvesting technology from body heat), which drove the two technology-driven projects at Organization B in Study 2 (B. Kim, Liu, et al., 2020) were used to generate examples of how the updated methods and tools could be used (see Appendix H).

**Research Limitations and Future Studies**

There were limitations of this dissertation research which address how interpret these results of this dissertation and to conduct the future studies related to this research.

In Study 1, few syllabi (n=5) and related class materials and activities (n=3) were able to be collected. Data synthesis with more syllabi and related materials would give a better understanding of how the contemporary ID education teach technology-driven design projects to students. Also, since most of the participants were from the U.S., the results of this study has limited applicability to the design education in other countries. Future studies should consider 1) collecting more syllabi and related materials about technology-driven design projects and 2)
collecting data from multiple countries to understand how design students in other countries are educated to contribute their design ability to the technology-driven NPD process.

In study 2, while Organization A and B are large (500 or more employees) and medium (11 to 50 employees) size contemporary TDOs, a case study of the role of design in a small TDO was not included in data collection. A future case study could be conducted with small TDOs, such as a start-up technology companies (less than 10 employees) to understand how designers contribute their ability in a small-size entrepreneur organization. Study results including a small TDO would provide better insights into the designer’s role in small, medium, and large size TDOs.

In study 3, while the researcher explained the concept of the process, methods, and tools to the experts, because most of the experts were new to the process (TPDP), methods, and tools, some of them had difficulty providing detailed feedback for certain methods. After updating the process, methods, and tools, future research should include allowing experts to engage with some activities using the introduced methods and tools. The researcher expects they would then be able to provide detailed feedback based on their experience. While providing an abstract level of explanation while introducing methods and tools allowed experts to give diverse feedback based on their own experience, some experts noted that providing examples of each method and tool would be beneficial for envisioning how the methods and tools would be used in a certain context. Future studies should consider providing examples of how the methods and tools are used.
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Appendix A

Institutional Review Board (IRB) Approval Letter for Study 1 (Chapter 5)

Sponsored Programs and Regulatory Compliance
Institutional Review Board (IRB)
Jennie Ofstein, Director
IRB-Director@ncsu.edu

NC STATE UNIVERSITY

Letter of Exempt Approval

Date: June 22, 2020

Title: Study of Teaching the Application of Technological Knowledge to Product Design in a Higher Education

IRB#: 19098

Dear Sharon Joines and Byungsoo Kim,

The research proposal named above has received administrative review and has been approved on September 13, 2019 as exempt from the policy as outlined in the Code of Federal Regulations (d.2, d.3). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.

2. Any changes to the research must be submitted and approved by the IRB prior to implementation.

3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please forward a copy of this letter to your faculty sponsor, if applicable.

Thank you.

Sincerely,

Jennie Ofstein
IRB Director
Institutional Review Board (IRB)
irb-director@ncsu.edu
919.515.8754
North Carolina State University
Appendix B

Study 1 (Chapter 5) Survey Questionnaires

Please select your occupation.

- [ ] Design educator
- [ ] Practitioner

Working Experience

1. Please select your current occupation.
   - [ ] Assistant Industrial Designer
   - [ ] Industrial Designer
   - [ ] Senior Industrial Designer
   - [ ] Design Manager
   - [ ] Adjunct professor
   - [ ] Associate Professor in Design Program
   - [ ] Assistant Professor in Design Program
   - [ ] Professor in Design Program
   - [ ] Etc. (please provide your job title ________ )

2. How long is your working experience in the industry as a designer?
   - [ ] 3-5 years
   - [ ] 6-10 years
   - [ ] 11-15 years
   - [ ] 16-20 years
   - [ ] More than 21 years
   - [ ] Not applicable

3. If you are currently working for a company, please select the type of company that you are currently working.
   - [ ] Technology-driven company (a company that has a clear focus on developing technology-related R&D products and use the technology as a source of developing future products)
   - [ ] Market-driven company (a company that develops new products based on the value that customers are interested in)
   - [ ] Design-driven company (a company that is expanding the role of designers in the NPD process to achieve innovation)
   - [ ] Other __________________________

The Importance of Technology in Design Process
4. How do you personally rate the importance of the application of technology to product ideas (e.g. finding an opportunity to apply VR technology to develop products and services)?

- Very important
- Important
- So-so
- Less important
- Not important

5. Explain why you feel this way (give examples from your work/teaching/networking/job openings, etc.)

6. How well do current design education/training prepare designers to develop a starting from advanced technology that meets the market/user need?

- The students have been very well prepared
- The students have been fairly well prepared
- The students have been somewhat prepared
- The students have been poorly prepared
- The students have been not prepared

7. Explain why you feel this way.

Teaching Technology Driven Approach in Design Program

1. What experiences have you had (i.e. a pedagogical approach/mentoring technique you used) that helped you teach (or mentor) someone to start with a technology to design a product? Provide an example if possible.

2. Based on your teaching and/or mentoring experience, what aspects of technology-driven development do students/mentees achieve easily?

Challenge/Suggestion of Teaching Technology Driven Approach

3. What pedagogical approaches or mentoring techniques do you think work best to teach students about how to achieve an innovation starting from technology to develop products that the public wants?

4. Regarding a course, in which students are instructed to start with a technology to design a product, what would be the challenge for design students to the technology to product ideas? Why do you think these would be problems?
5. Please write a description of the key points in a technology-driven design process that could help other designers just learning the process.

6. Do you have any concerns/thoughts about the course explained above (e.g. in which students are instructed to start with a technology to design a product)?

**Demographic information**

7. What is your sex? (Optional)
   - Male
   - Female

8. What is your age group?
   - 18 - 24
   - 25 - 34
   - 35 - 44
   - 45 -54
   - 55 -64
   - Over 65
Appendix C

Study 1 (Chapter 5) Interview Questions

1. Introduction
   - Can you briefly introduce yourself including your background, major and degree at your university?
   - If you have previous working experience, have you worked as a non-designer? How long? Have you worked as a designer? How long? And in which types of companies (e.g. tech-driven company)?
   - What is your age group (e.g. 18 - 24, 25 - 34, 35 - 44, 45 - 54, 55 - 64, or Over 65)?

2. Technology and Design
   - How do you personally describe the importance of the application of technology to product ideas in the design process (e.g. finding an opportunity to apply VR technology to develop products and services)? Why do you feel this way (give examples from your work/teaching/networking/job openings, etc.)?

3. Design education
   - How well do current design education/training prepare designers to develop a market/user need for advanced technology? Why do you feel this way?
   - What pedagogical approaches or mentoring techniques do you think work best to teach students about how to achieve an innovation starting from technology to develop products that the public wants? (i.e. develop a new course, internships, etc.)?

4. Technology-Driven Design Project
• Can you briefly explain the technology-driven design learning experience (e.g. a funded project, lecture, assignment etc.) that you experienced in school?

• What experiences have you had (i.e. a teaching approach/mentoring techniques you received) that helped you succeed in the class you took regarding designing a product or a service in technology-driven context? Provide an example if possible.

• Based on your technology-driven design learning experience, what aspects of the technology-driven design learning experience helped you to be a better designer?

• What was the challenge for you to understand core technology characteristics and utilize technology to generate product ideas? Why do you think this was a challenge for you?

• Based on your experience, could you please draw a technology-driven design process that could help other students to understand the process, making sure to write in key points (follow-up describe each step).

• Is there any concern or challenge to teaching this process in design education? Is format (course/studio/workshop) a concern? If yes, what would that be?
Letter of Exempt Approval

Date: June 22, 2020

Title: Study of User Experience: Technology to Product Design Process (TPDP) and Related Tools in Practice

IRB#: 20950

Dear Sharon Joines,

The research proposal named above has received administrative review and has been approved on April 14, 2020 as exempt from the policy as outlined in the Code of Federal Regulations (d.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.

2. Any changes to the research must be submitted and approved by the IRB prior to implementation.

3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please forward a copy of this letter to your faculty sponsor, if applicable.

Thank you.

Sincerely,

Jennie Ofstein
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Appendix E

Study 2 (Chapter 6) Interview Questions

Before turning on the recorder and beginning the interview:
I’m looking forward to learning from your experience. Thank you for completing the consent form on Qualtrics.

To protect your privacy and the privacy of others, I ask that you refrain from using your name or the names of others. You can refer the others through their role, such as “student,” “professor,” “colleague,” etc. If you accidentally name yourself or others, those names will be removed in the transcription process and will not be published.

Any questions before we begin?

1. Introduction

- **Background / working experience / age group**
  - **For students**
    - Can you briefly introduce yourself including your background, major and degree at your university?
  - **For practitioners**
    - Can you briefly introduce yourself including your position within your organization and how long have you been working there?
  - **For all participants**
    - What is your age group (e.g. 18 - 24, 25 - 34, 35 - 44, 45 -54, 55 -64, or Over 65)?

2. Experience in technology-driven projects

- **For students**
  - Can you briefly explain the technology-driven NPD projects that you are currently working on or have worked on?
  - Would you describe the main technologies driving the products in development?
  - What were the key features and characteristics of the technologies that helped you to move the projects forwards (i.e. to identify potential users and generate product ideas)?
  - What were the main challenges working on the technology-driven projects (i.e. understanding technologies, understanding potential end-users, and communicating with co-workers, etc.)?
  - What were the main takeaways that you learned from the projects?
  - Which approach, and/or mentoring helped you to move the projects forward?

- **For practitioners**
Can you briefly explain the technology-driven projects that you have recently worked/or are currently working on?

(For project manager/director) what was the project brief provided to the students?

What were the main technologies driving the products for the projects?

What are the key features and characteristics of the technologies that you think are important to develop the products for the projects?

What were the pros/benefit of working with Industrial Design students?

What were the main barriers/challenges to work with Industrial Design students on technology-driven projects? (i.e. having the students to 1) understand technologies, 2) explore potential end-users, 3) communicate with other stakeholders, 4) apply the technology in the form factor of working prototypes, etc.)?

Which approach, and/or mentoring helped you to guide/manage the students to efficiently move the projects forward?

3. Experience and/or the impact of the tools utilized in technology-driven projects.

For students

Can you sketch out the process of the technology driven projects (step-by-step, similar to the example shown below-the examples will be screen-shared to the participants via Zoom)?

Which stage was the most challenging for you and why?

There are different design tools to help you with the projects (i.e. mind map, user persona, slice of life, storytelling/storytelling, matching the characteristics of the technologies, potential user groups, and etc.). Please explain the tools that you used during the projects and in which phase(s)? How have the tools helped you to efficiently move the projects forward?

Among the tools used, which tool was the most (least) useful and why?

For each tool used, please explain how the tools contributed to the projects in the following 4 aspects:

i. Fluency: developing diverse product ideas/potential use-group
ii. Flexibility: the number of ideas that differ from each other based on some system of classification (e.g. different user groups and/or user personas)

iii. Originality: the degree of uniqueness of ideas from existing product ideas

iv. Feasibility: the degree of the possibility to be prototyped, manufactured and/or sold

- Do you have suggestions to improve the tools used?

- **For practitioners**
  - Can you sketch out the process of the technology driven projects (step-by-step, similar to the example shown below-the examples will be screen-shared to the participants via Zoom)?

  ![Project Process Diagram](image)

  - Which stage was the most challenging for you and why?
  - There are different design tools to help with the projects (i.e. mind map, user persona, slice of life, storyboarding/storytelling, matching the characteristics of the technologies, potential user groups, and etc.). Please explain the tools that were used for the projects and in which phase(s)? How did the tools help to efficiently move the projects forward?
  - Which tools were used for the projects and in which phase(s)?
  - Among the tools used, which tool was the most (least) useful and why?
  - For each tool used, please explain how the tools contributed to the projects in the following 4 aspects:
    - **Fluency:** developing diverse product ideas/potential use-group
    - **Flexibility:** the number of ideas that differ from each other based on some system of classification (e.g. different user groups and/or user personas)
    - **Originality:** the degree of uniqueness of ideas from existing product ideas
    - **Feasibility:** the degree of the possibility to be prototyped, manufactured and/or sold
  - Do you have any suggestions to improve the tools used?
Appendix F

Institutional Review Board (IRB) Approval Letter for Study 3 (Chapter 7)

Date: June 22, 2020
Title: Expert Review: Technology to Product Design Process (TPDP) and Related Tools
IRB#: 20972

Dear Sharon Joines and Byungsoo Kim,

The research proposal named above has received administrative review and has been approved on May 6, 2020 as exempt from the policy as outlined in the Code of Federal Regulations (d.2, d.8). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.
2. Any changes to the research must be submitted and approved by the IRB prior to implementation.
3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please forward a copy of this letter to your faculty sponsor, if applicable.
Thank you.

Sincerely,

Jennie Ofstein
IRB Director
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919.515.8754
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Appendix G

Study 3 (Chapter 7) Interview Questions

**Before turning the recording on and beginning the interview:**
I’m looking forward to hearing your feedback. Thank you for completing the consent form in Qualtrics.

To protect your privacy and the privacy of others, I ask that you refrain from using your name or the names of others in case you make examples in your feedback. You can refer the others through their role, such as “student,” “professor,” “colleague,” etc. If you accidentally name yourself or others, those names will be removed in the transcription process and will not be published.

Any questions before we begin?

**Demographic/working experience**

- Can you briefly introduce yourself including your position at your university (company) and how long have you been teaching (working)?
- How long is your working experience as a design educator (designer)?
- What is your age group (e.g. 18 - 24, 25 - 34, 35 - 44, 45 -54, 55 -64, or Over 65)?

**Process, methods, and tools review/evaluation**

Please see the shared screen to begin the interview. Please let me know if you cannot see the shared screen (note to IRB reviewer: please see below to review the example slides that will be shared with participants. While the content is subject to be changed, the structure and the level of the information that will be presented to the participant will be similar to the following slides).
Interviewer notes: I would like to briefly introduce you to the background and the purpose of the study. As the importance of design in the new product development process has been underscored, the number of designers hired by technology companies have been increased. While there has been an increasing need to include designers in the conversation of NPD in technology companies, there seems to be little guidance regarding how to maximize the designers’ contribution in technology-driven context. Also, nowadays, many Industrial Design Departments in universities have been collaborating with technology organizations and working on new product development (NPD) projects in a technology-driven context (technology-driven NPD projects). While Industrial Design students are familiar with the NPD projects initiated based on users' needs, many students do not have confidence working on technology-driven NPD projects.
Interviewer notes: Design education needs to teach design processes and associated methods and tools to help students to be ready to be designers to maximize their contribution in the companies they will work for. Companies need designers to be actively engaged in New Product Development (NPD) process. The double diamond design model is a well-structured process that guide designers to develop new products with user-centeredness. This model is widely used in design education and it starts from users. While this model is applicable to the later steps of the technology-driven NPD process, it does not guide designers in the front-end of the technology-driven NPD process, which starts with technology.
Interviewer notes: The model shown in this slide is the newly developed design process model applicable to the front end of technology-driven NPD process (explain the process). Please let me know if you have any questions about this model.
Interviewer notes: The checklist shown in this slide is the newly developed tool that is applicable to the front end of the technology-driven NPD process, especially in the Project Discussion phase (explain the details of the checklist). Please let me know if you have any questions about this tool.
Interviewer notes: The model and the information shown in the following slides are the newly developed method applicable to the front end of the technology-driven NPD process, especially in the Learning Technology phase (explain the details of the method). Please let me know if you have any questions about this method.
Related Methods and Tools 2: Technology Knowledge Visualization

Examples

1. Yield Stress Fluids
   - Substances remain solid at rest and begin to flow when mechanical forces are applied.
   - Given by instructors/technology organizations
   - Generated by students

2. Shear-thickening Fluids
   - Substances are solid at rest but become thin when mechanical forces are applied.
   - Given by instructors/technology organizations
   - Generated by students

3. Rod-climbing Effect
   - Substance climbs up the rod as the rod spins.
   - Given by instructors/technology organizations
   - Generated by students

Assessment

Please discuss/evaluate the developed method considering the given aspects below.

- Importance of UCD
- Motivation
- Technology Application Limit
- The Role of Instructor
- Different Aspects of Technology
- Consideration Beyond Users
- W/Different Disciplines
- Outcomes
- Administration
Interviewer notes: The diagram and the information shown in the following slides are the newly updated/developed tools applicable to the front end of the technology-driven NPD process, especially in the Use Case Exploration phase (explain the details of the tools). Please let me know if you have any questions about the tools.

Interviewer notes: Explain the tool and answer any questions from the participant.
Interviewer notes: Explain the tool and answer any questions from the participant.

Assessment

Please discuss/evaluate the developed tool considering the given aspects below.
Interviewer notes: The tools shown in the following slides are the newly updated/developed tools applicable to the front end of the technology-driven NPD process, especially in the Find Valuable Application of Technology phase (explain the details of the tools). Please let me know if you have any questions about the tools.

**Related Methods and Tools 4: Potential User Exploration**

**Slice of Life**

- **Alert from the device**
- **Insert related photo**

**SITUATION**

Describe the scenario with potential challenges that the users would encounter (the best way of developing it is having an interview with potential users).

**Opportunities**

- Applicable technologies: XX

Identify the opportunities to solve the potential challenges described above

Interviewer notes: Explain the tool and answer any questions from the participant.
Assessment

Please discuss/evaluate the developed tool considering the given aspects below.
Appendix H

Updated TPDP and Related Methods and Tools with Examples

Follow this link

(https://docs.google.com/presentation/d/1PZ7AM_94a6xsd5z6eW2RDyy0cFtaLv3Ff23UJ4ay5f4/edit?usp=sharing) to view and download the updated TPDP and related methods and tools.
TPDP application Example

Scenario: A technology company proposed a 8 week technology-driven project to ID program at a university.
Tool/Method 1: Technology and Design Checklist

01 Categorization of technology
- Application to Everyday life vs. Professional Career
- Closeness of technology to End-Users
- Physical/non-physical Elements

02 Collaboration opportunities with other disciplines
- Graphic/Interaction Design, Computer Engineering
- MBA/Business/Marketing
- Textile, Industrial Engineering, Mechanical Engineering, Electronic Engineering
- Contribution of Different Disciplines

03 Administration
- Time Management
- Project Scope and Outcome
- Student Management
- Budget
- Resources

Role of Instructor
- Explain clearly about the purpose of this activity
- Help the students to understand the key attributes of the technology, not to simply create visualizations
- Pose interesting questions about the key attributes of technology that will be essential to understand to connect potential users and develop product ideas

Tool/Method 1: Technology and Design Checklist Example

01 Categorization of technology
- Application to Everyday life vs. Professional Career: Everyday life (office workers with asthma), open to explore other possibilities
- Closeness of technology to End-Users: Very close
- Physical/non-physical Elements: Physical elements and UX interaction

02 Collaboration opportunities with other disciplines
- Disciplines: Textile and Electronic Engineering
- Main Contribution from Different Disciplines: Design (aesthetics, potential user exploration), textile (fabric component), Electronic Engineering (develop circuit board with sensors, power connection)

03 Administration
- Time Management: 8 weeks
- Project Scope and Outcome: Explore potential product ideas (expect to develop products 5-10 years from now) from TEG and related sensors (not identified at this point) beneficial for potential users, Gantt chart, 1 storyboard integration with technology, students will learn TEG technology and methods of communicating with different engineers through this project
- Student Management: Masters of Industrial Design students (n=2) with ID instructor (n=1), Electronic Engineer (n=1) and Textile engineer (n=1) will collaboratively work with the students weekly
- Budget: $1,000 (purchasing materials) + $250 (travel expense) + $4,000 (ID students salary)
- Resources: TEG (2 sets), related sensors (as needed), and circuit boards (4 sets) will be provided to the ID students for exploration, Industrial Designer from Samsung will be available for critique, identified terms to learn the technology: TEG, search engine: ScienceDirect
Tool/Method 2: Simplified Visualization of Technology

- Given by instructors/technology organization
- Generated by students
- Critique from instructors/technology organization

Role of Instructor
- Explain clearly about the purpose of this activity
- Help the students to understand the key attributes of the technology, not to simply create visualizations
- Pose interesting questions about the key attribute of technology that will be essential to understand to connect potential users and develop product ideas

Tool/Method 2: Simplified Visualization of Technology Example

Activities
- Lecture given by instructors/technology organization
- Visualization generated by students
- Critique from instructors/technology organization

- TEG is flexible
- Heat leakage is an issue
- Thick encapsulation is an issue

- Temp. gap between body heat and the outer temp. will create energy
- Bigger temp. gap will generate greater energy
Tool/Method 3: Contextualization of the Tech. and Beyond

<table>
<thead>
<tr>
<th>Advantage/ Limitation of Technology</th>
<th>Unintended Consequence/ Impact of Tech.</th>
<th>Tech. and Politics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summarize the advantages/ limitations of Technology</td>
<td>Summarize the unintended consequence and/or Impact of Technology</td>
<td>Summarize technology related politics and policies</td>
</tr>
</tbody>
</table>

**Strengths**
- 

**Weaknesses**
- 

**Opportunities**
- 

**Threats**
- 

**Role of Instructor**
- Find a good resource to help students consider the unintended consequences and the impact of the technology on society.

---

Tool/Method 3: Contextualization of the Tech. and Beyond Example

<table>
<thead>
<tr>
<th>Advantage / Limitation of Technology</th>
<th>Impact/ Unintended Consequence of Tech.</th>
<th>Tech. and Politics</th>
</tr>
</thead>
</table>
| **Technology Characteristic 1: Energy harvesting**
  Advantage
  - No charging terminal necessary
  Limitations
  - Larger temperature gap needed for bigger energy
  - Heat leakage poses a problem
  - Thick encapsulation is an issue
  - Not effective in warm/hot temperature
| Impact
  - Wearable device without battery
  - 24/7 health monitoring
  - Charging device
  - Effective to athletes
| **Technology Characteristic 2: Flexibility**
  Advantage
  - Large area harvesting is possible due to flexibility
  Limitations
  - Flexible, not stretchable
| Unintended Consequence
  - More effort required to charge the device than normal wearable devices in warm weather
  - Malfunction due to creative ways of charging (e.g., putting the device in freezer, or hot/cold water)
  - If the device is expensive, most people would be unable to afford it.
  - Health monitoring data and privacy
|
Tool/Method 3: Contextualization of the Tech. and Beyond Example

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge without battery</td>
<td>Larger temperature gap needed for bigger energy</td>
</tr>
<tr>
<td>Flexible</td>
<td>Heat leakage poses a problem</td>
</tr>
<tr>
<td>Simple fabrication</td>
<td>Thick encapsulation is an issue</td>
</tr>
<tr>
<td></td>
<td>Not effective in warm/hot temperature</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearable device without battery</td>
<td>More effort is required to charge the device than normal wearable devices in a room temperature</td>
</tr>
<tr>
<td>24/7 health monitoring</td>
<td>Malfunction due to creative ways of charging (e.g. putting the device in freezer, or hot/cold water)</td>
</tr>
<tr>
<td>Effective when exercising</td>
<td></td>
</tr>
</tbody>
</table>

Role of Instructor
- Explain clearly about the purpose of this activity: to explore potential user groups who will benefit from the technology
- Give guidance regarding sources to generate ideas about potential users, either through secondary research online or through direct interaction with people

Tool/Method 4: Potential User Exploration

Brainstorm potential target users as much as you can and document the potential users.
Tool/Method 4: Potential User Exploration Example

- Single
- Married
- Don't like sports
- Like sports
- Outdoor
- Indoor
- Treadmills
- Yoga
- Body weight
- Weight lifting
- Swimming

Ppl. in 30
Ppl. in 40
Ppl. in 50
Ppl. w/ asthma

Tool/Method 5: Mash-up Users and Tech.

Potential User 1
Potential User 2
Potential User 3
Potential User 4
Potential User 5
Potential User 6

Context 1
Context 2
Context 3
Context 4
Context 5
Context 6
Context 7
Context 8

Technology Characteristic 1:
Advantage
Limitations

Technology Characteristic 2:
Advantage
Limitations

Technology Characteristic 3:
Advantage
Limitations

Technology Characteristic 4:
Advantage
Limitations

- Encourage mapping with non-design disciplines together
- Guide students to start thinking about unknown products or services that have not yet been identified in the mind map

Role of Instructor
Tool/Method 5: Mash-up Users and Tech. Example

- **Wearables**
  - Office works
  - House works
  - Sleeping
  - Treadmills
  - Yoga
  - Body weight
  - Weight lifting
  - Walking/Running
  - Swimming
  - Scuba Diving

- **Technology Characteristic 1:** Energy harvesting
  - Advantage: No charging terminal necessary
  - Limitations:
    - Larger temperature gap needed for bigger energy
    - Heat leakage is challenging
    - Thick encapsulation is challenging
    - Not effective in warm/hot temperature

- **Technology Characteristic 2:** Flexibility
  - Advantage: Large area harvesting is possible due to flexibility
  - Limitations:
    - Flexible, not stretchable

---

Tool/Method 6: Prioritization of Potential Users

1. Early 30 Office Workers: Highlight the potential users focusing on at the current/near future phase of the project
2. Teenagers w/Asthma: Present other potential users as a future product development
3. Early 20 Athletics: Present other potential users as a future product development
4. Late 40 Housewife: Present other potential users as a future product development
5. Early 70 Retired Elderly: Present other potential users as a future product development

- **Potential Users**
  - User Profile/Context
    - Provide reasons based on the findings from previous activities
  - Reason
    - Provide reasons based on the findings from previous activities
### Tool/Method 6: Prioritization of Potential Users Example

<table>
<thead>
<tr>
<th>Potential Users</th>
<th>User Profile/Context</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 30 Office Workers</td>
<td>Office Workers who enjoy swimming everyday</td>
<td>Impact of Tech. Preventing over workout would be necessary</td>
</tr>
<tr>
<td>Early 20 Swimmer</td>
<td>Swimmers who need to intensively swim everyday</td>
<td>Maximising the use of Tech. There will always be adequate temperature gap between the pool water and users</td>
</tr>
<tr>
<td>Early 20 Athletics</td>
<td>Athletics who need to run over an hour everyday</td>
<td>Impact of Tech. Preventing over workout would be necessary</td>
</tr>
<tr>
<td>Teenagers</td>
<td>Teenagers who enjoy swimming everyday</td>
<td>Maximising the use of Tech. Body Heat will be higher when running</td>
</tr>
<tr>
<td>Early 70 Retired Elderly</td>
<td>Early retired elderly who likes swimming everyday</td>
<td>Maximising the use of Tech. There will always be enough temperature gap between the pool water and users</td>
</tr>
</tbody>
</table>

### Tool/Method 7: Design Criteria and Insight

**User Sequence:**
- Stage 1
- Stage 2
- Stage 3
- Stage 4
- Stage 5
- Stage 6
- Stage 7

**Comments from potential users (use user journey map to define challenges and opportunities):**

**Design Criteria:**
- Develop design criteria based on the findings while interacting with potential users.

**Insight:**
- Develop insights based on the findings while interacting with potential users (see below as an example).

**Role of Instructor:**
- Find an opportunity to interact with potential users.
- Encourage non-design students to participate in certain sections.
Tool/Method 7: Design Criteria and Insight Example

User Sequence:
- Arrive at gym locker
- Change to swimming suit
- Warm-up before swimming
- Swimming
- Alert from device
- Stop swimming
- Extract water from swimming suit
- Shower & Change

<Device is expensive, so I will not leave it in a locker room>

<Device is in a secure spot and not distracting my warm-up exercise and swimming>

<Alert will gently but will clearly remind me to stop swimming in 3, 2, and 1 min>

<Can take the electrical part out and use a water extractor>

<Device is expensive, so I will not leave it in a locker room>

Design Criteria
- The electrical part need to be easily mounted/unmounted to extract water from the swimming suit located in a secure spot without disturbing swimming and warm-up exercises
- The alert need to be clear enough for the swimmer (i.e. sound feedback via earbud) at least more than once and the last one should last until the monitored health is within stabilized range

Insight

Tool/Method 8: Slice of Life

Stage Number

Insert related photo

SITUATION

Describe the scenario with potential challenges that the users would encounter (the best way of developing it is having an interview with potential users)

Opportunities/Product Ideas

Applicable technologies:

Identify the opportunities and develop ideas to solve the potential challenges described above. If it is a collaboration project with Engineering program, collaborate with engineers to identify the applicable technologies and develop product ideas.

Role of Instructor

- Encourage non-design students to participate in certain sections
Tool/Method 8: Slice of Life Example

**SITUATION**

While swimming, there will be a notification alerting the user of the need to use an inhaler based on the heart rate tracking. User will notice the alarm and stop swimming. User will find and use an inhaler.

**Opportunities/Product Ideas**  
Applicable technologies: TEG, Water-proof, ECG/PPG

Combination of vibration and sound feedback would not be enough while swimming.  
Alert screen from goggles would be an efficient method.