Exploring Design Thinking for Instructional Practice

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ABSTRACT

This dissertation entitled, *Exploring Design Thinking for Instructional Practice*, is situated in the cognitive rigor of design thinking instructional practice and engineering design-based capstone courses. The content of the instructional practice connects with educators employing a wide range of intellectual activities or cognitive tasks in formulating their curriculum. Key attributes of design thinking were identified through a focused literature review with an emphasis on theoretical propositions applicable to instructional practice. This dissertation contains two manuscripts: (a) an exploration of the theoretical literature related to design thinking explicating implications for instructional practice, and (b) a case study involving a small, purposive, sample of undergraduate faculty members teaching engineering design-based courses with findings broadly applicable to design processes in college curricula. The faculty participants in the case study were educators at a large, public, research-intensive university in the southeastern region of the United States. The data analyses involved triangulation of semi-structured interviews conducted with faculty participants and their design-based course materials, including syllabi and lesson plan materials. The study's thematic findings were not tied to engineering but rather course design, design process, and course management. The findings show the utility of artifact creation for learning with understanding for everyone, not just engineers and other traditional designers. Overall, the dissertation contributes to pedagogy that promotes student-centered engagement for

learning with understanding. It recommends design thinking instructional practice for inclusion in designing and making artifacts of constructed knowledge for learning with understanding engagements across the academy.

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GENERAL AUDIENCE ABSTRACT

This dissertation entitled, *Exploring Design Thinking for Instructional Practice*, integrates a wide range of intellectual activities also referred to as cognitive tasks of student-centered design thinking activities. In this dissertation, these tasks are useful for tackling problems that are not well-defined, such as, open-ended, real-world problems. Examples of this pedagogy are useful for educators considering and/or implementing design thinking in their curricula. This dissertation contains two manuscripts: (a) an exploration of the theoretical literature related to design thinking from theory to artifact making, and (b) a case study involving undergraduate faculty members teaching design thinking in design-based courses. The study's faculty participants were educators teaching engineering capstone courses at a large, public, research university in the southeastern region of the United States. Their students design and make solutions for open-ended, real-world problems that are not in textbooks and do not have "right" answers. The study's data collection phase involved interviews with the faculty participants and course materials (syllabi, lesson plan materials, handouts, and course websites). Data analysis produced three themes: course design, design process, and course management. These themes suggest that a design thinking instructional practice belies perceptions that design thinking is tied exclusively to engineering and other traditional design disciplines. The findings suggest that design thinking pedagogy engages students in creation of artifacts, learning with understanding, hands-on

experiential learning in iterations, use of productivity tools, teamwork, and new starting points when outcomes do not meet expectations. Overall, the findings suggest design thinking pedagogy promotes student-centered design thinking activities.

Dedication

Dreams
By Nikki Giovanni

in my younger years
before i learned
black people aren't
suppose to dream
I wanted to be…then as i grew and matured
i became more sensible
and decided I would
settle down
and just become
a sweet inspiration
Source: The Collected Poems of Nikki Giovanni (2003)

This dissertation is dedicated to my late husband, Michael J. Hunt, for standing by me from 1974, when we met until his final day. Many years ago, I shared my dream of earning a Ph.D. with my husband. Michael's encouragement was not only in words but his purpose for seeing not only his dreams come true, but my dreams flourish. No matter the dream - crazy, challenging, epic, or costly (personally, professionally, and financially) - Michael stood by me. His commitment to my dreams kept me from the fear of difficulty or feelings of not belonging; like others who have not walked as far as I have to complete a lifelong Ph.D. dream or faced race, gender, SES, and other character-building challenges. I cherish the words he shared in conversation with me just a few hours before his final moment on May 7, 2020, "Joanie, I'm right behind you with my hand on your shoulder. You've got this!" Michael, rest, my beloved best friend and husband, I've got this!"

My dedication is also to my father and mother, the late, John H. Banks, Jr. and Marian I. Banks. No one believed in education more than my parents. They gifted 10 children with a love of learning, private education in Atlanta/Detroit Catholic schools, and transportation to and from colleges in an old, station wagon that barely ran but always got you there. My Dad was admitted to Meharry Medical College before completion of his senior year at Morris Brown College in Atlanta, GA. Meharry is one of the oldest and largest historically black academic health centers dedicated to educating physicians. Although admitted in 1948, my Dad was unable to attend because he had to continue working the night shift at the US Post Office and day shift at a bookstore AND a drug store to feed, clothe, and shelter his family. Dad, this doctorate honors your dream to become a doctor. Mother, this doctorate honors your gifts as the family's 4 ft 10 in, super-teacher-MOM. Thank you, Mother, for giving your children a love of learning - "in-home reading, writing, math, science, and many academic tools to ensure that we were prepared to live independently and according to our dreams and efforts."

I must also dedicate this dissertation to one of my 6 brothers, John Anthony. When I was 5 years old, I came home from Kindergarten one day quite upset because my teacher would not call on me when my hand was raised. Anthony advised me to "Tell Daddy about that!" My father took me by the hand and walked me down the street, mostly to cool me down and stop the flow of tears. My father told me about a famous (*negro)* man named, 'Dr. Bouquet, a college professor at a big college in the east.' It was that day that I told my Dad, 'I want to be a college professor!' My father and I talked about my dream of becoming a college professor over the years that passed after that memorable walk and talk. He entrusted my brother, John Anthony, with my dream. Anthony reminded me frequently over the years about going after that Ph.D. dream. Strangely, 60 years later, while a Ph.D. student walking in the Graduate Life Center at Virginia Tech (VT), I came across a poster about a graduate honor society named in honor of Dr. Edward A. Bouchet. I immediately reconnected with my Dad's story about "Dr. Bouquet" and called my brother. Anthony just laughed and said, "Joanie, this is no coincidence, Daddy thought Dr. Bouchet's name was pronounced, "bouquet." Although my application was not accepted to become a member of the Edward A. Bouchet Graduate Honor Society, I have the closure of a lifelong dream. Thank you, big brother, for keeping my dream to earn a doctorate alive all of these years.

It takes a Village to Raise A Child (African Proverb)…My village —Coltrane (my son) and Tavia (my daughter); my living siblings (John Anthony, Peter Claver Bernard, Paula Elizabeth, Barbara Faye, Angela Therese, Christopher Francis, Vincent Patrick, and Gerald Martin (my heart)); Casey; Jason; Anita, Jessika, Bianka, Sandra; Regina Preyer Poole (best friend since third grade); Glynda Melonson Moorer, MD (best friend since 5th grade); my husband's keepers of my Ph.D. progress, Donna and Thelma; Banks, Hunt, Baker, Threatt, Jones, Smutnak, Hardin, & Gamez Families; Malia, Loretta; Sandra I., James Monroe I.; Alexis; Boago Nkwe; and many friends, especially Mrs. Hattie Mitchell, one of my mother's closest friends (94 years old and called every month to check on my progress to Ph.D.).

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I arrived Fall semester 2015, Dr. Stephanie Adams, at the time, a Department Chair in the Virginia Tech (VT) School of Engineering admitted me to the Ph.D. Program in Engineering Education and changed my life! The dissertation journey has fostered my passion for lifelong learning and allowed me to contribute to my field as a researcher, educator, innovator, and motivator of students within and across disciplinary boundaries.

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Thanks to everyone from California to Virginia for extending support, time, and trust in my ability to achieve a Ph.D. in Education, Curriculum, and Instruction, with an emphasis in Educational Psychology, and graduate certificates earned in Engineering Education and Cognition of Education. I’ve finally completed my goal that has been a dream for over 6 decades! Thank You! Thank You! Thank You! I’ve Got This!

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Introduction

Design thinking instructional practices and interests in design thinking for instructional practice are growing (Cassim, 2013; Kimbell, 2011; Luka, 2014). Although design thinking as a profession and instructional approach originated in design fields, such as architecture, engineering, and art, "nowadays [it] is applied in many fields" (Luka, 2014, p. 63). "The main idea is that the ways professional designers' problem-solve is of value to firms trying to innovate and to societies trying to make change happen" (Kimbell, 2011, p. 285). As a concept, design thinking practice and awareness are changing as "the changing conception of design products points the way to new opportunities opening up for designers to traverse traditional design disciplines and to enlarge their range of activity" (Cassim, 2013, p. 192). Characteristics of design thinking and tangible activity enable a wide range of design products or artifacts of constructed knowledge that are observed beyond design fields. According to Simon (1996), "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p. 111). Yet, educators face challenges as they advance design thinking instructional practices to prepare and educate students for the domain of knowledge and valued utility that crosses traditional disciplinary boundaries today.

The domain of design thinking is widening. Educator's today face myriad instructional challenges when developing courses that have pedagogical learning progressions and content to supplement the demands of a complex and fast-changing world. Because there exists a wide range of design thinking applications, a wide-range of perceptions and debates about instructional practice and design thinking persist. Some researchers believe that design thinking facilitates students' interdisciplinary knowledge, knowledge creation, cognitive operations to deal with different problem types, diverse perspectives, and improves learned knowledge (Luka, 2019; Sharples et al., 2016; Stempfle & Badke-Schaub, 2002). Others engage in an ongoing debate regarding approaches of design thinking instructional practice, design processes and competences useful for teaching in fields within and beyond the traditional design culture (Johansson-Sköldberg et al., 2013; Johansson & Woodilla, 2010). Therefore, although the domain is widening, "just what design thinking is supposed to be is not well understood" (Kimbell, 2011, p. 288). Thus, as the domain of design thinking broadens, there are researchers who still argue that a lack of clear understanding exists for educators considering and/or new to the concept of design thinking for instructional practice (Johansson & Woodilla, 2010; Kimbell, 2011; Rylander, 2009). The primary goal of this dissertation is to contribute to design thinking for instructional practice research and practice.

Many educators are embedding design thinking attributes in instructional practice today. The first manuscript in this dissertation explores the theoretical literature related to design thinking in order to provide implications for instructional practice. The second manuscript in this dissertation explores design thinking instructional practice, preparation, and context through the use of a case study involving a small, purposive, sample of undergraduate faculty members teaching engineering design-based courses.

The first manuscript establishes theoretical attributes of design thinking grounded in the literature. The literature search involved scholarly literature obtained from academic electronic databases, journals, published books, and Google Scholar. The resulting foundational literature for the first manuscript provided historical connections and a wealth of peer-reviewed articles and several books on design, design thinking, and human problem solving. The literature review spans some five decades from Simon's (1969) seminal work *The Sciences of the Artificial* (1969,

1996) to Luka's (2019) journal article "Design Thinking in Pedagogy: Frameworks and Uses." Although the terminology *design thinking* was pioneered by Rowe (1987) some 18 years after Simon's seminal work, a growing research base focused on design thinking in academic and management realms has been productive. Attributes of design thinking are embedded in a wide range of applications in which designers, not necessarily traditional engineers, architects, and artists, practice the skills and tools of designers to create artifacts of constructed knowledge. A gap exists in the research regarding design thinking instructional practice as informed by attributes of design thinking grounded in the literature. Therefore, the overriding research question for the case study described in the second manuscript of this dissertation was "What can be learned from faculty perceptions of instructional practice with regard to design thinking that engages students in design thinking activity?" This question was answered through semi-structured interviews and document content analysis of the participants' course materials. In addition, the study contributes to clarity of understanding design thinking instructional practice to determine to what extent design thinking theoretical contributions are embedded in the course design, design process, and course management as clear and definite knowledge structures (Dorst, 2011; Johansson & Woodilla, 2010; Luka, 2019).

The second manuscript is a case study designed to understand what can be learned from faculty of design-based courses about their perceptions of instructional design and practice with regard to students' design thinking engagement and activity. The data were gathered from a small, purposive sample of participants who were instructors of undergraduate engineering design capstone courses. The instructors formulated and prepared lesson plans and guided students through real-world, open-ended problems. Teamwork was a big component of the hands-on, experiential learning experiences, while industry partners provided feedback and some participated on student design teams. There were no textbooks and learning-by-doing provided learning with understanding.

Manuscript 1

Design Thinking Instructional Practice: Theory to Artifacts

Abstract

In this manuscript, the theoretical literature related to design thinking provides implications for instructional practice. Design thinking techniques are frequently explored to construct knowledge for learning with understanding when academic boundaries are blurred; such as, situations involving open-ended real-world problems, transdisciplinary program development, and/or emergent content knowledge. This manuscript draws on the theoretical roots of design thinking to bridge artifact creation of constructed knowledge to learning with understanding. When problem solving is situated in hands-on, experiential learning processes with embedded design thinking propositions, student learning outcomes are influenced by "designerly" ways of knowing versus memorization practices. The first section of the manuscript provides an introduction to design thinking theoretical contributions for artifact creation successes using iteration to refine ideas/solutions. Subsequently, design thinking for instructional practice is aligned with design/design thinking attributes grounded in the literature. Lastly, a summary of answers to research question and recommendations for future study are provided.

Keywords: artifact making, design thinking, designerly, emergent content knowledge, knowledge construction, and open-ended problems

We live in a highly technical, complex, and fast-changing world. Because of "increased mobility, the world-wide web, and instant information, teachers and students find themselves in previously unknown places, contexts, and situations" (Luka, 2014, p. 63). These unknown places come from educators' questions regarding emergent content knowledge, such as, "what to teach, why it is worth knowing, and how it relates to other propositions, both in theory and practice" (Shulman, 1986, p. 8). This curiosity for understanding emergent content knowledge often introduces complexities for attainment of the desired knowledge and interest in knowing how to teach ways of knowing or constructing knowledge, especially in the context of the real-world gathered from open-ended problems. "Knowledge is generated and accumulated through action. That is, knowledge is used to produce work, and work is evaluated to produce knowledge" (Razzouk & Shute, 2012, p. 333). In many fields, design thinking is embedded in the work to produce knowledge as a process of designing and making "artifacts that have desired properties" (Simon, 1996, p. 111).

There is a growing interest in design thinking embedded in instructional practice to promote creative ways of addressing student-centered learning and preparation for a world of rapidly changing information and technology (Kinbell, 2011; Luka, 2014). Educators are tasked with preparing "young people to learn more complex and analytical [21st century] skills [they] must learn to teach in ways that develop higher-order thinking and performance" (Darling-Hammond, 2009, p. 46). There are, however, challenges associated with convincing educators to expand their certainty of domain-specific curricular knowledge with the uncertainties of emergent content and related interdisciplinary knowledge. A key challenge for educators interested in emergent content knowledge is that it embodies content never previously learned. Educators need promising ways to close inescapable gaps encumbered by rapidly changing resources, technology, highly competitive expectations, and emergent theoretical propositions. Educators require skills for keeping pace with emergent content knowledge worth knowing, albeit never learned, yet considered essential for students' academic preparation.

Historically, the concept of "design thinking" originated in design disciplines. The designer's practice in traditional design disciplines is characterized as thinking and embracing the design process to attain desired end goals. Design disciplines include fields such as engineering, architecture, and graphic design. Some researchers and practitioners associate the purpose of education in engineering to "graduate engineers who can design and that design thinking is complex" (Dym et al., 2005, p. 103). However, design and design thinking are in every problem-solving challenge, foreshadowing "what might be," repairing things and concepts around us that need fixing, design-led changes in the world, workarounds and/or substitutions for unsuccessful plans, brainstorming ideas on project teams, or making lemon-aid when life gives you lemons. In any field or life experience, design and design thinking knowledge are generated and acted on, whether as a user, builder, experimenter, innovator, evaluator, or whatever is one's preference.

Today, there exists a wide range of issues related to preparing students for the world they will enter - interdisciplinary, open-ended, real-world, problems, textbooks, no textbooks, sociotechnical, community life, ethics, diversity, equity, inclusion, classroom learning techniques (asynchronous, synchronous, hybrid, face-to-face, distance learning, and virtual classrooms), contemporary instructional technology, and so much more. As Henriksen et al. (2017) point out, "The problems educators face in practice are complex, diverse, and often difficult to address" (p. 140). Educators are looking for ways of improving instructional practices through creative approaches to student-centered learning activities with "distinct things to know, ways of knowing them, and ways of finding out about them" (Cross, 1982, p. 221). Design thinking is frequently considered a great technique for teaching and learning processes in the context of complex problem solving involving distinct things to know and communicate (Archer, 1979; Dorst, 2011; Luka, 2014).

There are a number of good reasons to be interested in design thinking. It is recognized as "a paradigm that is considered to be useful in solving many problems in different areas: both in development of design projects and outside of traditional design practice" (Irbīte and Strode, 2016, p. 1). According to Koh et al. (2015), educators are paying attention to implications of design thinking in education because

> The design dimension is characteristic of human and civilized culture and accordingly embed design thinking as an integral part of education. Fostering design thinking among today's learners is essential for the knowledge age, much of which is driven by technological advances. Design thinking seeks to utilize knowledge and practices to find viable solutions that would meet the needs and interests of people in the context of the challenges of contemporary society. (p. 12)

Design thinking reflects the various disciplines in which it has been implemented, and as a result, the ways in which it can be conceptualized and implemented varies by educational setting. Depending on the application (context or adaptation), design thinking can be defined as a technique, process, innovation technique, methodology, problem-solving activity, or even constructivism learning approach (Luka, 2014, p. 63). It can be positioned as a tool or process utilizing intuition and reflective iterations for creating new products and services (innovation) (Koh et al., 2015; Luka, 2014). Others position it as the way designers think to solve problems and create meaningfulness.

Shared Language: Active Learning and Design Thinking

Fundamentally, active learning and design thinking share a number of intellectual activities based on thinking and learning-by-doing. They offer a sharp contrast to traditional lectures and instructional practice. Students of these methods are not passively receiving information but rather immersed in a process designed for active participation in the learning process. Active learning and design thinking are confronted by similar confusion as well. Both lack a single definition, as many teachers, researchers, and practitioners are in search of that universal description for categorization of the instructional practice (Fauset et. al, 1998; Prince, 2004). And with certainty, the framework of both concepts supports a variety of learning forms that actively engage students in instructional activities "involving doing things and thinking about what they are doing" (Bonwell & Eison, 1991, p. 5).

Design-based learning, problem- and project-based learning, experiential learning, discovery learning, learning with understanding, engineering design, innovation, entrepreneurship, and multi-disciplinary learning are instructional practices found in teaching emerging content knowledge – and more good reasons to be interested in active learning and design thinking. Experiential learning theory (ELT) is a series of design thinking situations or activities that "help explain how experience is transformed into learning and reliable knowledge" (Kolb, 2014, p. xxi). Is this not active learning? Discovery learning is active learning that "involves active participation on the part of the learner on activities designed to illustrate a concept or process rather than the sake of doing something active" (Svinicki, 1998, pp. S4-S5). Is this design thinking? All of the methods listed model cognitive learning, an underlying principle in common with active learning and design thinking.

Literature findings identify a tremendous upside for design thinking knowledge construction strategies that can convince educators to expand their domain-specific curricular knowledge with emerging content knowledge. The benefits to educators interested in knowing how to supplement their instructional practice with emerging content knowledge addresses a number of complexities. Educators are interested in being able to understand, develop, and design courses that impart highly desirable knowledge on their students. Design thinking for knowledge construction offers a method for engaging students as active participants in the learning process of making sense of complex and/or emergent subject-matter. It offers the opportunity to change students' passive engagement in the learning process for active engagement. It elevates student-centered learning to higher-order thinking through implementation of designer's practices applied to problem solving.

This manuscript is structured into four sections. The first section introduces the theoretical contributions of design thinking starting with seminal thinkers of the 20th century. This section also discusses educational theorists contributing theoretical evidence of design thinking as an academic discipline (Archer, 1979). It includes an introduction to the design thinking growing research base contributing intellectual rigor and teachable schemas. The second section provides the basis of a descriptive model for design thinking knowledge construction. The descriptive model organizes theories of design thinking knowledge construction based on design attributes grounded in the literature. The third section, Design Thinking for Instructional Practice: Theory to Artifacts, discusses the interconnection of design theory, design process, and design thinking instructional practice in creation of constructed knowledge artifacts. The section identifies benefits of design thinking constructed knowledge artifacts for teaching and learning complex problem-solving in academic settings. And the final section suggests recommendations for future empirical study.

Design Thinking: Seminal Thinkers

The seminal thinkers of design thinking are theorists Herbert Simon (1969) and Peter Rowe (1987). Although Simon preceded the introduction of design thinking terminology by some 18 years, many researchers connect his definition of design to the applicability of design and human thinking, or design thinking in problem solving. Simon (1996) stated,

> Everyone designs who devises courses of action aimed at changing existing situations into preferred one. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company of a social welfare state. (p. 111)

According to Simon, the intellectual activity of design is a process in which information is gathered that is constructive in the discovery of producing material artifacts of a problem solution. Design is a process of intellectual activity that results in breaking down disciplinary boundaries to construct a "common core of knowledge that can be shared by the members of all cultures" (p. 136). Simon's definition of design is a process that describes what the designer is doing to solve complex problems (p. 114). The designer "crosses many fields of human endeavor around complex problems and creative solutions" (Henriksen et al., 2017, p. 141). Everyone is a designer engaged in the cognitive tasks of creating artifacts of constructed knowledge (Simon, 1996).

Herbert Simon (1969). Herbert Simon's (1969) seminal work *The Sciences of the Artificial* (1969) provides theoretical concepts that describe the intellectual activity of design. The activities that Simon defines are at the core of all professional training. They characterize a process for how to make the desired artifacts that satisfy all human needs. As Simon's focus is on all human needs, it follows that his definition of a designer is all-inclusive: "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p. 111). Simon's seminal work is a thesis on the science of the design, a process for making artificial objects that represent and formulate human goals and purposes as opposed to natural objects of the science of nature.

The science of design is a rich collection of Simon's reasoning on design and the design process of the artificial world. He describes the goals of the artificial world. They are to adapt the inner world of existing or constructed knowledge artifacts to the outer world of knowledge discovery for design and making new knowledge artifacts. The artificial world is therefore positioned at the interface between the inner and outer environments of the design process.

Simon's design process is aimed at finding satisfactory actions of precedence and sequence within a framework of systematic paths to new worlds of knowledge. Simon's vision was to "take information from the world outside and transform it into knowledge…knowledge of many domains and often even expertness" (p. 99). His vision reflected a rational learning system of knowledge construction that "human beings carry around in their heads" (pp. 98-99). His system "can be extended to a method of learning 'by-doing'" (p. 105). The framework of his vision has the ability to provide analysis, synthesis, academic respectability, and "the ability to communicate across [different subject matter] fields—the common ground—involved in creating a design and what takes place while the creation is going on" (p. 137).

The design thinking review describes how to participate "as designers of design processes" that create pathways to new worlds of knowledge (Simon, 1996, p. 137). The descriptive model, as shown in Figure 1, is an abridged version of Simon's information-processing system that handles "importing and exporting [content knowledge] from one intellectual discipline to another" (p. 138). The descriptive model diagrams a rational process of intellectual activity for design and making artifacts of knowledge for evaluation of academic respectability prior to communication of meaningful knowledge gained that include: theory of human thinking, process of design, utility theory (a theory of evaluation), and theory of design (See Table 1).

Theory of Human Thinking provides the *analysis* of information to design artifacts that fit our human needs. It is a rational process with understanding the end goals and building on prior knowledge. The artifacts represent technology, information resources, and products of new worlds of knowledge. It is the science, art, and overall understanding of knowledge that relates the subject matter knowledge to Shulman's pedagogical content knowledge (PCK; Shulman, 1986).

Process of Design is the information-processing system. It is a system that *synthesizes* how to design and make knowledge artifacts that represent and formulate transformative learning. The system includes all of the intellectual activity or active learning ideas and actions used to decide on a direction to take. The intellectual activity is a non-linear, reflective process of actions (feedback loops) that vary from simple actions to complex. Engagement in the process of intellectual activity is the *practice* of active learning. Active learning as practice is "participation in meaningful activities and thinking about what the learner is doing" (Bonwell & Eison, 1991). And because the process of design is reflective, the active learning engagement needs to "find decisions that are "good enough" that satisfice" (Simon, 1996, p. 27). The designer, therefore, needs awareness of alternatives of (cognitive) actions as criteria of satisfaction or creativity and end goal(s) can be compromised.

Simon (1969) presented seven stages of the design thinking process: (a) define, (b) research, (c) ideate, (d) prototype, (e) choose, (f) implement, and (g) learning (as cited in Luka, 2014). Simon's early seminal work on the process of design thinking influenced other subsequent models, some of which reintroduce the terminology of these seven stages.

Academic Respectability is an *evaluation* to determine that the process of design is "a body of intellectually tough, analytic, partly formulated, partly empirical, and [wholly] teachable doctrine" (Simon, 1996, p. 113). The evaluation is this criterion of academic respectability that ensures meaningfulness and utility of the knowledge gained.

Theory of Design is what the designer *communicates* about the design process that led to lessons learned, meaning making, and knowledge artifacts. Simon's (1996) definition of design "concerned with how things ought to be, with devising artifacts to attain goals" (p. 114). The theory of design communicates whether or not the attainment of goals met "how things ought to be" (p. 114). This communication of outcomes as declarative statements and taxonomy brings the designer into contact with new worlds of knowledge—the common core of knowledge that can be shared (Simon, 1996, pp. 111-137).

The components of design are activities that work together to make discoveries. "The test that something has been discovered is that something new has emerged that could not have been predicted with certainty and that the new thing has value or interest of some kind" (Simon, 1996, p. 106). Design thinking knowledge construction is a practice of discovery. Simon refers to this practice as an approach to "discover interesting new concepts and interesting conjectures about them" (p. 106). The practice is construction of knowledge artifacts.

Peter Rowe (1987). Peter Rowe's Design Thinking (1987) was published about 18 years after Simon's Sciences of the Artificial (1969). Rowe's theory builds on Simon's cognitive activities of making things [artifacts] for commonplace usefulness. He introduces an intuitive design process, a departure from Simon's rational design process. His intuitive design process has similarities of experiential learning.

Rowe pioneered the terminology, design thinking, in his seminal work of the same name, *Design Thinking* (1987). Rowe's theory builds on Simon's cognitive activities of making things [material artifacts] to satisfy human needs, but departs from the rational design process. He introduces an intuitive design process that synthesizes the practices of traditional designers into a circular, spiraling, model of four phases – analysis, synthesis, evaluation, and communication.

The four phases of Rowe's iconic model define practices of action learning, "an educational approach whereby people come together as peers to solve problems, analyze, implement proposed solutions, monitor and learn from results" (Pedler, 2011, p. 21). His active learning word choices represent design thinking phases that transform problems, well-defined and ill defined, into ways of understanding content knowledge, such as gaining an understanding of emergent content knowledge never before learned. Rowe's (1987) model presents design thinking as a decision-making process that accommodates "many different styles, each with individual quirks as well as manifestations of common characteristics" (p. 2). His focus was on many different styles that align with researchers' beliefs that design thinking is not a single definition. Rowe also believed that design thinking is a collection of descriptive properties used to make sense of new and unexplored problem types – well-defined and not well-defined. His description of well-defined design problems is "those for which the ends, or goals, are already prescribed and apparent" (p. 40). He also described problems that are not well-defined, "both the ends and the means of the solution are unknown at the outset of the problem-solving exercise" (p. 40). He projects the discovery of making or designing new things (artifacts) onto his design thinking model. The model address four active learning design activities – analysis, synthesis, evaluation, and communication.

Rowe's (1987) design thinking model is a configuration that resembles a spiraling spring that expands and contracts when squeezed. The symbolism of spiraling might represent disentangling a challenging puzzle, deep concentration, or an unfolding journey that refines big ideas and thoughts. Rowe's design thinking model is also a bottoms-up design that begins with abstract knowledge situated visually at the bottom of the diagram shaped like a spring and concrete knowledge at the top. This demonstrates that his model not only has spiraling characteristics for visual thinking. It resembles shrinking, stretching, and spiraling characteristics around a core of four concepts– analysis, synthesis, evaluation, and communication (see Table 2).

The first characteristic of Rowe's (1987) model, *Analysis,* defines a design thinking process that is more spontaneous for automated thinking versus prolonged evaluation. "Intuitive and automated responses precede more cognitive and effortful evaluations, they may dominate judgments and choices when designers have too little time for deliberate reflection" (Kim & Ryu, 2014, p. 544). Analysis is understanding the problem or emergent content knowledge worth knowing. It involves being able to formulate the problem and end goal(s) and incorporating the spontaneity of sequentially spiraling through the four concepts of design thinking to create artifacts of meaning making. Analysis is a *Human Thinking* process of exploring possibilities, and "our own thoughts, our processes of judging, deciding, choosing and creating artifacts [of constructed knowledge]" (Simon, 1996. p. 137). Analysis builds and assesses big ideas and thoughts to make sense of the new and unexplored things.

Synthesis is the second characteristic of Rowe's (1987) model. Synthesis is the characteristic that brings together the designer's discoveries useful for designing and making artifacts of constructed knowledge. Synthesis, is the collection of new content knowledge for use in the desired problem-solving design process. The cognitive tasks are a series of hands-on, experiments that test new ideas and build from prior knowledge to preferred new knowledge. The iterations are events stored in long-term memory as episodic data. New things learned are blended with the old in a dynamic, action-based or activity-based learning. The *Process of Design* addresses problem types that are well defined, not well-defined, and everything in between. in a design thinking process that is iterative (circular).

Evaluation is the third concept in Rowe's (1987) model. His design thinking model relies on two distinct theses in the development of theory about design thinking as mental problem solving from the perspective of this architect and theorist: (a) a mechanistic type of doctrine ("associationism"), and (b) activity that reference the kinds of problems confronting [architectural] designers. Rowe's design thinking and evaluation is influenced by Simon's design thinking process. Rowe's evaluation of design thinking is a logical progression of "schemata, or organizational frameworks for structuring meaningful information" (Rowe, 1987, pp. 44-49). Rowe's evaluation of design uses analogy to serve a designer's purposes for more than a single project.

And finally, *communication* is the fourth concept in Rowe's (1987) model. *Communication* provides the language of a cognitive system to support "'designerly' ways of knowing, things to know, and ways of knowing them" (Cross, 1982, p. 221). Communication shapes and expresses images of the design ideas after evaluation and iteration for refinement.

In summary, Rowe's model revisits Archer's (1979) research on design process that concludes:

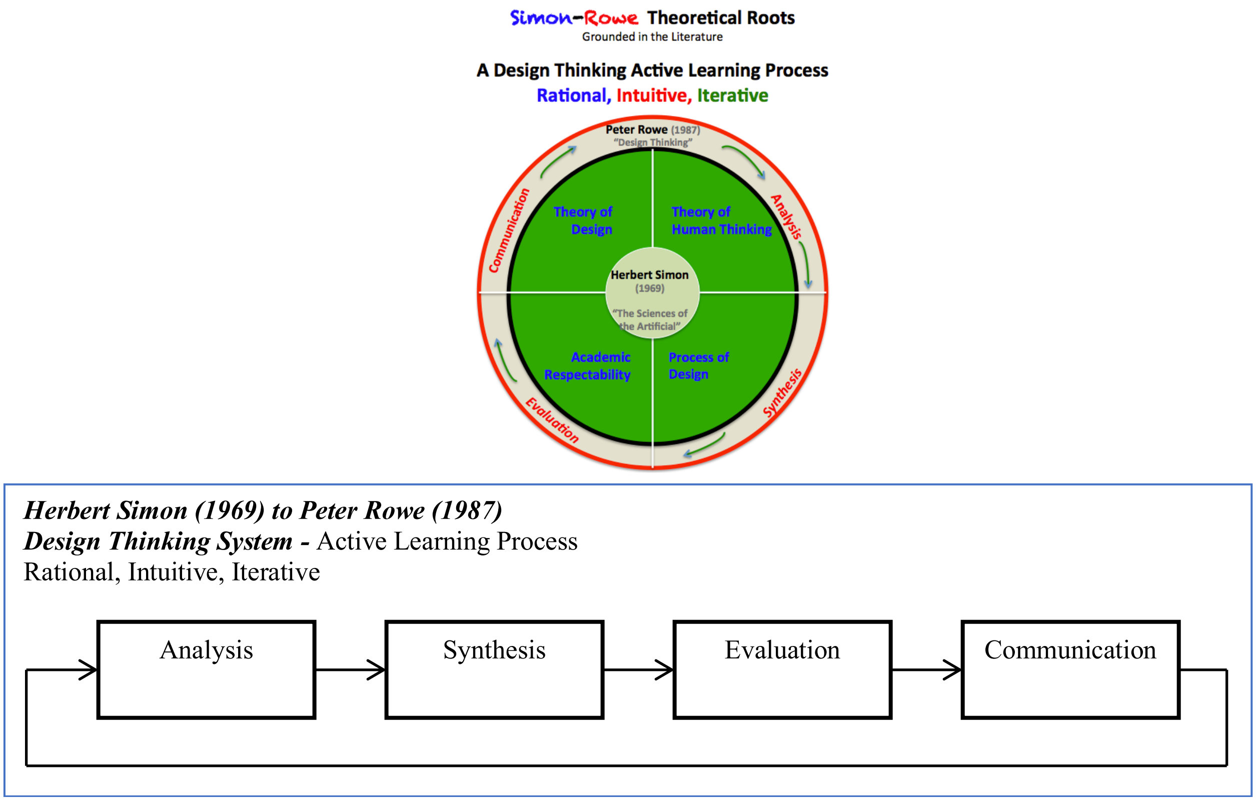
> There exists a designerly way of thinking and communicating that is both different from scientific and scholarly ways of thinking and communicating, and as powerful as scientific and scholarly methods of enquiry, when applied to its own kinds of problems. (p. 17)

Rowe's model emphasizes the concepts, analysis and synthesis, to further clarify Archer's designerly ways of thinking. His model accomplishes this objective by supporting Archer's beliefs that designerly thinking is an interconnection of cognition concepts as opposed to a "separation of analysis from synthesis, all of which was perceived by the designers as being unnatural" (Archer, 1979, p. 18). Thus, Rowe's model provides a visual that depicts Archer's proposition on the provision of communication to provide the language of a design thinking cognitive system that shapes and conveys images of the designer's ideas. Rowe is modelling Archer's proposition about

> The way designers (and everybody else, for that matter) form images in their mind's eye, manipulating and evaluating ideas, before, during, and after externalizing them, constitutes a cognitive system comparable with, but different from, the verbal language system. (Archer, 1979, p. 18)

"Theories, models, from design methodology, psychology, education, and process" are based on this communication or model of design thinking as terminology (Dorst, 2011, p. 521). See Figure 1, a visualization of design thinking terminology shown as a model that spirals around the four concepts described above.

Figure 1. Design Thinking Theoretical Roots: Seminal Thinkers
(Banks-Hunt, J., 2020)



Design Thinking Knowledge Construction: Growing Research Base

A number of educational theorists are aligned with the design thinking seminal thinkers, Simon (1996) and Rowe (1987). The aligned educational theorists contribute to theoretical propositions grounded in the foundational literature of design and design thinking attributes. Many theorists, researchers, and practitioners are building on a growing research base that expands upon design thinking principles and cognitive activities. The expanding principles and cognitive activities strengthen the structure of the design thinking active learning system established in the seminal works of Simon and Rowe.

The seminal thinkers of design and design thinking, introduced in the previous section, are theorists Herbert Simon (1969) and Peter Rowe (1987). The educational theorists to be introduced in this section include John Dewey (1958); Horst Rittel & Melvin Webber (1973); Bruce Archer (1979); Nigel Cross (1982); Donald Schön (1983); Klaus Krippendorff (1989); Richard Buchanan (1992); Clive Dym (2005); and others. The section is an alignment with the seminal thinkers (Simon and Rowe) and their contributions to the theoretical roots of a design thinking knowledge construction descriptive model of theoretical contributions. The purpose of the descriptive model is to present the propositions to "recognize that they are better understood if they are organized in some coherent form, lodged in a conceptual or theoretical framework" (Shulman, 1986, p. 11). The model provides a tool useful for instructional practice recall or retrieval of strategic elements of design thinking aligned with theoretical propositions. These propositions are an array of intellectual activity alternatives that enhance the design thinking active learning system.

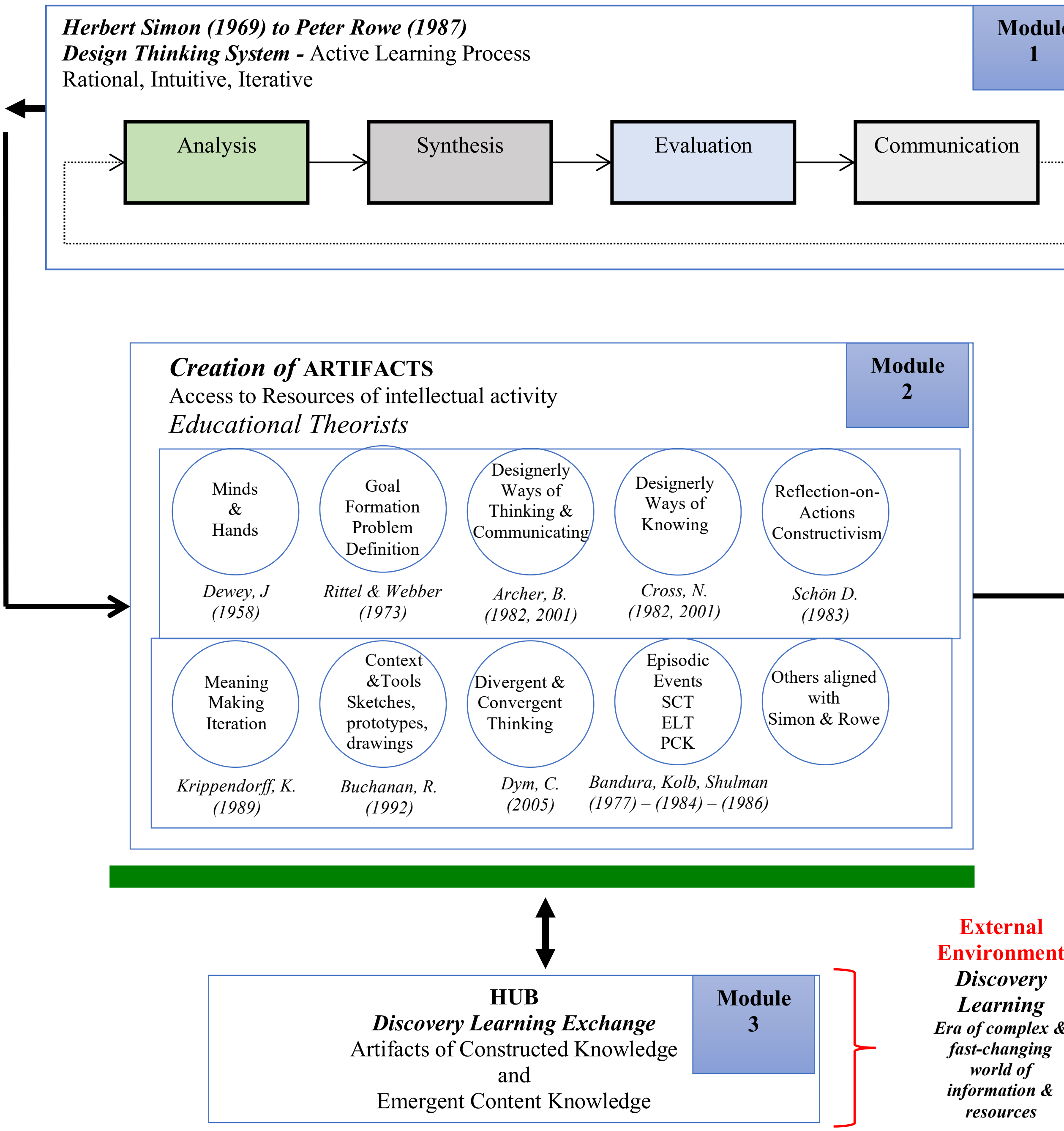
The educational theorists, researchers, and practitioners reinforce and expand Simon's argument by providing propositions in which the design thinking process comes together along the three attributes of design – theory, process, and instructional practice. Figure 2 displays the growing research base of educational theorists, researches, and practitioners contributing to *Design Thinking Knowledge Construction: A Descriptive Model.*

Design Thinking Knowledge Construction: A Descriptive Model

The goal of the proposed design thinking knowledge construction descriptive model is to support educators' interests in intellectual activity or knowledge growth empowered by meaningful learning. The descriptive model provides a guide for educators interested in their students learning a lesson with understanding, or meaningfully. According to findings produced in laboratory experiments, learning a lesson with understanding is an instructional approach that causes students to (a) learn more rapidly with understanding than by rote learning, (b) retention is sustained over longer periods of time, and (c) knowledge artifacts can be transferred better to new tasks (Mandler, 1967; Simon, 1996). The model organizes design thinking knowledge construction to provide flexibility for future growth and/or enhancements/modifications of curricula because it is built on a growing research base.

The design thinking knowledge construction descriptive model consists of three modules: (a) the core theoretical foundation of design thinking active learning informed by Simon (1969, 1996) and Rowe (1987), (b) the growing research base of design thinking process and instructional practice, a related collection of intellectual activity propositions, and (c) the artifact creation center or hub for exchanging learning outcomes of the internal environment (constructed knowledge artifacts) with open-ended, real-world problems and/or emergent domain knowledge (the external environment). The descriptive model assembles these components of design thinking active learning into a structure useful for design thinking instructional practice in education, general use (see Figure 2).

Figure 2. A Design Thinking Knowledge Construction Descriptive Model (Banks-Hunt, J., 2020)



The active learning environment of a design thinking knowledge construction descriptive model operates as a system. It is analogous to an intelligent processing system in the way that the model processes human thinking information to inform "how it adapts itself, through individual learning and social transmission of knowledge" (Simon, 1996, p. 76). Modules 1 and 2 are central to the intelligent design thinking and processing system. One of the modules provides a cyclical process of design thinking activity, and the other, access to the intellectual activity propositions or stored resources of the design thinking system. The problem solver engages modules 1 and 2 to create artifacts of constructed knowledge. Module 3 is the hub or external interface between creation of artifacts and the external environment of real-world problems or emergent content knowledge.

Module 1. *Module 1* is the core theoretical foundation of design thinking active learning is based on seminal theorists Simon (1996) and Rowe (1987). *Module 1* is a synthesis of design and design thinking theoretical roots. Generally speaking, Simon's thesis is a "complex system made up of a large number of parts that have many interactions… in such a system, the whole is more than the sum of the parts" (Simon, 1996, pp. 183-184). The parts are theories and concepts that implicate the premise of design and human thinking theories and other tools of the complex system of rational human thinking and design. And when interconnected with Rowe's design thinking terminology and design process model, design thinking activity is shaped by an experiential process, a whole system, involving four parts—synthesis, analysis, communication, and evaluation of constructing knowledge (Rowe, 1987). Simon and Rowe strengthen the core of a design thinking active learning system and make it rational, intuitive, and iterative. The design thinking active learning system is useful "as more knowledge is acquired about more subjects…becomes more complex because it grows in size… [and] human beings carry around in their heads knowledge of many domains" (Simon, 1996, p. 99).

Module 2. *Module 2* comprises resources of the internal active learning environment. It is an array of resources available for creation of artifacts. The resources are a collection of theoretical propositions that provide scaffolding for learning things "already known to others from learning things that are new to the world" (Simon, 1996, p. 105). The resources comprise cognitive strategy alternatives that aid the design process of constructing artifacts of knowledge. The design thinking alternative actions or intellectual activity propositions supplement the design thinking active learning system per desired needs. The intellectual activity propositions are grounded in the literature of design thinking having an emphasis on potential instructional practice resources.

Module 3. *Module 3* is the model's hub of discovery learning exchange between creation of artifacts and external sources, such as, open-ended, real-world problems or emergent content knowledge. According to Herbert Simon (1996), "an artifact can be thought of as a meeting point—an "interface"—between an "inner" environment, the substance and organization of the artifact itself and an "outer" environment, the surroundings in which it operates" (p. 6). When applying Simon's reasoning, the hub of discovery learning exchange becomes the meeting point or interface between the internal environment of active learning and external environment of discovery learning through open-ended, real-world problems and emergent content knowledge. The hub of discovery learning exchange is the interface for exchange of learning things "already known to others from learning things that are new to the world" (p. 105).

In summary, the descriptive model's emphasis on knowledge construction is focused on affecting the value of learning meaningfulness and knowledge growth that is different from textbooks and rote learning. It is a learning pathway useful for educators' curriculum development of learning with understanding, such as, meaningful learning of emergent content knowledge. “Every teacher knows that there is a profound difference between a student learning a lesson by rote and learning it with understanding, or meaningfully” (Simon, 1996, s. 101). The design thinking knowledge construction model is a response to rapidly changing information resources, needs, and demands of instructional practice. It communicates a design thinking system grounded in the literature of seminal thinkers and a growing research base of educational theorists and researchers. The model is robust, general-purpose, and useful for a wide range of educators’ development of curriculum for learning in a complex and fast-changing world. It is not as customized as vertical design thinking process models, such as, IDEO, Stanford d.school, INTEL, and others focused on specific problem-solving agendas that are also grounded in design thinking literature.

Design Thinking Instructional Practice: Theory to Artifacts

The broadened definition of a designer is evident in the artifacts of design thinking that surround us – urban planning, agricultural technology in foods, clothing design, recycling, transportation, public policies, hand-held devices, educational reform, technology education and engineering curricula, cyber security, business management, medicine, and decision-making. Design thinking is in every human-made product and service to satisfy human needs. Discovery learning to prepare students for a complex, fast-changing world is a benefit of the design thinking knowledge construction descriptive model.

In many workplaces today, an integration of academic disciplines is required. People require approaches to think about content knowledge that goes beyond knowledge of the facts or concepts of their domain expertise. To address these needs in our complex and fast-changing society, the educator’s dimensions of subject-matter knowledge are changing. Educators are designing their courses with an integration of technology, creativity, and innovative programmatic curricula. All of these issues for educators challenge instructional practice and require scaffolding and approaches to "design things to know, ways of knowing them, and ways of finding out about hem" (Cross, 1982, p. 221). Design thinking for knowledge construction is frequently suggested to construct artifact of knowledge by broadening the course content and instructional practice.

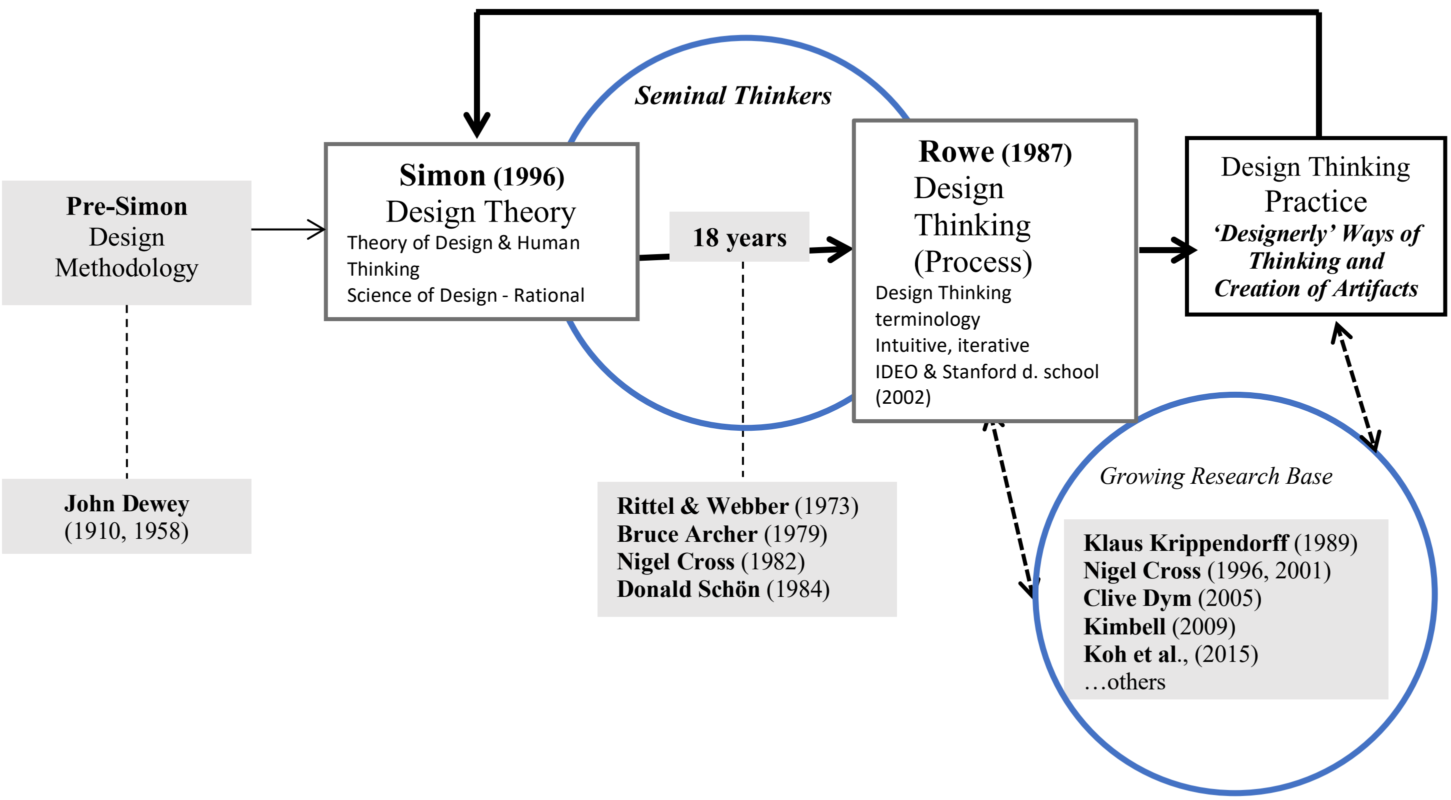
Design thinking knowledge construction resides at the high intellectual level of the human-made world - the artifacts that represent and formulate knowledge constructed to satisfy human needs. Examples of human-made artifacts include: education, STEM, architecture, business, medicine, pharmaceuticals, housing, food, clothing, transportation, space travel, music, entertainment, trinkets, gaming, the world clock, and mono-, multi-, and trans-disciplinary pedagogy. Many believe that the wide use of design thinking contributes to fragmented understandings that stem from the lack of a single definition, varying characteristics, or the underlying discourse regarding different processes (Dorst, 2006, 2010, 2011; Kimbell, 2011; Owen, 2007).

Design thinking knowledge construction is useful in curricula, domain expertise, and emerging pedagogical content knowledge. It enhances the student's ability to choose between different academic paths and career options and for creating knowledge for different personal interest paths (Anderson, 2012, p. 43). The design thinking descriptive model synthesizes research findings on effective knowledge growth from emergent content knowledge for instructional practice. Crossing the line of once narrowly scoped discipline-specific worldviews to multidisciplinary content integration describes the more complex and analytical skills required of educators. They "must not only be capable of defining for students the accepted truths in a domain. They must be able to explain why a particular (new) proposition is deemed worth knowing, how it relates to other propositions, both within the discipline and without, both in theory and in practice" (Shulman, 1986, p. 9).

The design thinking knowledge construction descriptive model benefits instruction of emergent content knowledge that possibly goes beyond the teacher's domain expertise. Curriculum development of this nature often recognizes the need to cross disciplinary boundaries knowledge and instruction of students whose domain interests demonstrate advance learning in areas of emergent content knowledge. Transdisciplinary content knowledge is one such area. It "transcends the narrow scope of disciplinary world views through overarching synthesis" (Gibbs, 2015, p. 24). Transdisciplinary content knowledge crosses disciplinary boundaries to engage learning in a more complex, messy, real-world situations that addresses open-ended problems that are not well defined.

This need supports a growing research base that builds on the utility of design thinking for knowledge construction in instructional practice. This utility is realized in a descriptive model that is a nonlinear topology. The descriptive model is a tool organized as a system of three interconnected design attributes grounded in the literature: design *theory*, design thinking *process*, and design thinking *practice*. The theory drives process, process drives practice, and practice drives creation of artifacts as well as new starting points (iterations) on active learning outcomes. The attributes of the descriptive model are organized to contribute specific elements of the designer's actions for creating artifacts of problem-solving solution(s)/alternative(s) (see Figure 3).

Figure 3. Design Thinking Nonlinear Topology: Growing Research Base (Banks-Hunt, J., 2020)



Structurally, Simon and Rowe are the inner-most elements and the growing research base of theorists, researchers, and practitioners are the outer-most elements of the design thinking active learning system. The system is rational, intuitive, and iterative. Simon (1996) contributed foundational theoretical principles and cognitive activities based on his thesis *The Science of Design*. Rowe (1987) contributed design thinking terminology framed in a circular (spiraling) process of problem solving for iterating and refining design ideas based on his design thinking terminology. Together, Simon and Rowe provide the theoretical roots of design thinking for knowledge construction, a growing research base.

Design thinking for knowledge construction builds on a "cocoon of information stored in books and in long-term memory that we spin about ourselves" (Simon, 1996, p. 110). It involves intellectual activity useful for scaffolding the design activity of creating artifacts of constructed knowledge. Design thinking knowledge construction scaffolding encompasses episodic learning events that are a logical bridge from prior knowledge (domain subject knowledge) and rote learning (traditional academic preparation) to content knowledge growth worth knowing (emergent content knowledge). The logical bridge also promotes efficacy and motivation, how we think, cognitive activities, and pedagogical content knowledge.

The attributes of design/design thinking grounded in the literature – theory, process, and instructional practice - work together to provide the procedural aspects of the design thinking process to create artifacts of knowledge construction for problem solving. Simon's (1996) goals of making artifacts and "devising courses of action aimed at changing existing situations" become reality with published design thinking terminology (p. 111). Communication of design theory and process, meaning making, and design process knowledge construction and architectural artifacts, provides a social transmission communication's vehicle. The social transmission vehicle is in observations and presentations of lessons learned. Communication propositions provide theories, models, methodology, psychology, education, and lessons learned. Communication goals are to present or summarize the courses of action aimed at changing existing situations. These AHA moments communicate a point in the design thinking process in which synthesis, analysis, and evaluation premises have been met.

The contributions of educational theorists explain the successes of design thinking for knowledge construction in a broad range of disciplines: engineering, architecture, art, medicine, business, IT, social sciences, political science, economics, and science, technology, engineering, and mathematics (STEM) education, and others. Educational theorists have shown their support of design thinking as intellectual activity. About the mid-1960s, educational theorists introduced propositions to broaden the strict limitations of design thinking in traditional disciplines. This shift redefined who the designer is, how to make material artifacts, and how to design. Herbert Simon (1996) argues, "engineers are not the only professional designers" (p. 111). Rowe was an architect and therefore uses the attributes of design to show how the designer's big ideas shape discoveries or possible solutions. Design thinking is the "particular orientation that preoccupies the designer" (p. 34). The four concepts or procedural aspects of the design process embark on a series of episodes in which the designer participates in a "'to and fro' movement" throughout the meaning making process. The meaning making process is the discovery of explorations, reflections, and evaluations. This discovery is particularly useful for emergent content knowledge deemed worth knowing for instructional practice and student learning outcomes. A number of educational theorists have provided cognitive activities or intellectual activities aligned with the design thinking knowledge construction descriptive model displayed in Figures 2 and 3. In brief:

John Dewey (1958) focused on progressive education and learning experiences that involve the minds and hands working together. He is recognized for awareness and understanding for the social aspects of learning. He uses conversations (communication) and interactions with others as integral aspects of learning. His emphasis on the experiences of using our hands and minds to create episodic events is key to analysis, synthesis, evaluation, and communication of design thinking. His seminal work, "How We Think" connects "learn-by-doing" to the four-stages of the Simon-Rowe design thinking process (Dewey, 1910, 1958). Dewey's propositions include, but are not limited to, construction (p. 91), systematic thinking (p. 78, 81), reflective activity (pp. 71-72, 78), inquiry (asking questions), suspended judgment until thinking is concrete (pp. 38, 138).

Horst W. J. Rittel and Melvin M. Webber (1973) presented propositions that emphasize goal formulation and problem definition. They stepped away from the rational, scientific, approaches to design introduced by Simon. By the early 1970s, Rittel and Webber's theory of wicked problems became the new intellectual activity of design. Solutions to problems of the wicked type were no longer limited to (rational) approach (Rittel, 1988).

Bruce Archer (1979) focused on *Design as Discipline* (1997) for "development of things and systems …as the purpose of design activity in general education" (Archer & Roberts, 2009, p. 55). Archer invested a lot of time in exiting models of the design process. He learned that these models were never completely accepted by traditional designers because they were typically descriptive of the design process as a logical or mathematically organized visual configuration or topology (Archer, 1979). He examined widely accepted characteristics of design problems that were complex or not well-defined to determine a number of requirements and the compatibilities or lack of compatibility with one another. He discovered that human beings found effective ways of dealing with problems, especially ones not well-defined, that caused the designer to vacillate "between the emerging requirement ideas and developing provisions ideas" (p.17). This and other findings resulted in belief in a novel concept. Archer believed there "exists a designerly way of thinking and communicating that is both different from scientific and scholarly ways" (p. 17). Archer's beliefs have influenced the impacts of design process and promoted "designerly" ways of problem solving.

Nigel Cross (1982, 2001, 2006) introduced the propositions of "designerly ways of knowing." He argued that "design has its own distinct 'things to know, ways of knowing them, and ways of finding out about them" (Cross, 1982, p. 221). Cross applied the characteristic of "the 'aha' experiences of having understood the idea" (Krippendorff, 1989, p. 13), as a key point in the design thinking process in which synthesis, analysis, evaluation, and communication come together. He attempts to distinguish the epistemology of design or designerly ways of knowing from the sciences on the one hand and arts and humanities on the other" (Koh et. al., 2015, p. 2). He highlights knowledge growth that reflects designing ways of knowing academic rigor.

Donald Schön (1983) introduced propositions pivotal to design thinking—reflection-on-actions and constructionism. Other intellectual activity propositions that Schön introduced include intuitive processes, reflective practices (a major contribution to field of design), and knowing-in-action, artistic and creative ways to negotiate complex situations.

Klaus Krippendorff (1989) introduced propositions of meaning making and iteration. He is another proponent of the 'aha' moment of attainment of end goals reflects making sense of things occurs; cognitively constructed meaning; iteration; circular sense-making process, and transition from a fuzzy image or abstract understanding to increasingly meaningful distinctions that contribute to concrete knowledge.

Richard Buchanan (1992) introduced propositions that involve placements (the context), tools, and iteration. His circular processes build on engagement of reflection-on-actions to solve wicked problem, using designers (drawing, sketching, modeling, simulating, researching, and etc.), and design thinking academic respectability. For wicked problems that are not well-defined, “the problem for designers is to conceive and plan what does not yet exist” (p. 18), in a challenging open-ended solution opportunity.

Clive Dym (2005) introduced the propositions of divergent and convergent thinking. Dym addresses the challenges that design is hard to learn and even harder to teach. He proposes asking questions as a starting point. Systematic questions are useful for analyzing a problem to reach truthful answers. Knowledge resides in the questions that diverge and converge as the design process unfolds. Different questions take place at various stages of the design thinking process. Dym’s premise is “convergent questions operate in the knowledge domain, whereas divergent questions operate in the concept domain. Design thinking is seen as a series of continuous transformations from the concept domain to the knowledge domain” (Dym et al, 2005, p. 105).

Finally, the literature identifies three theoretical frameworks - experiential learning theory (ELT), pedagogical content knowledge theory (PCK), and self-efficacy theory - that strengthen design thinking knowledge construction. Although not design thinking theories, Social Cognitive Theory (Bandura, 1989), ELT (Kolb, 1984), and PCK (Shulman, 1986), contribute to theoretical evidence supporting arguments the elevation of design thinking to the level of an academic discipline (Buchanan,1992; Cross, 2001; Rowe, 1987; Simon,1996).

Design Thinking Artifacts of Teaching and Learning

In many workplaces today, an integration of academic disciplines is required. Educators require approaches to think about content knowledge that goes beyond knowledge of the facts or concepts of their domain expertise. The dimensions of subject-matter knowledge in teaching are also emerging with the integration of technology, creativity, and innovative programmatic curricula. All of these issues for educators challenge instructional practice and require scaffolding and approaches to "design things to know, ways of knowing them, and ways of finding out about them" (Cross, 1982, p. 221). Design thinking for knowledge construction is suggested.

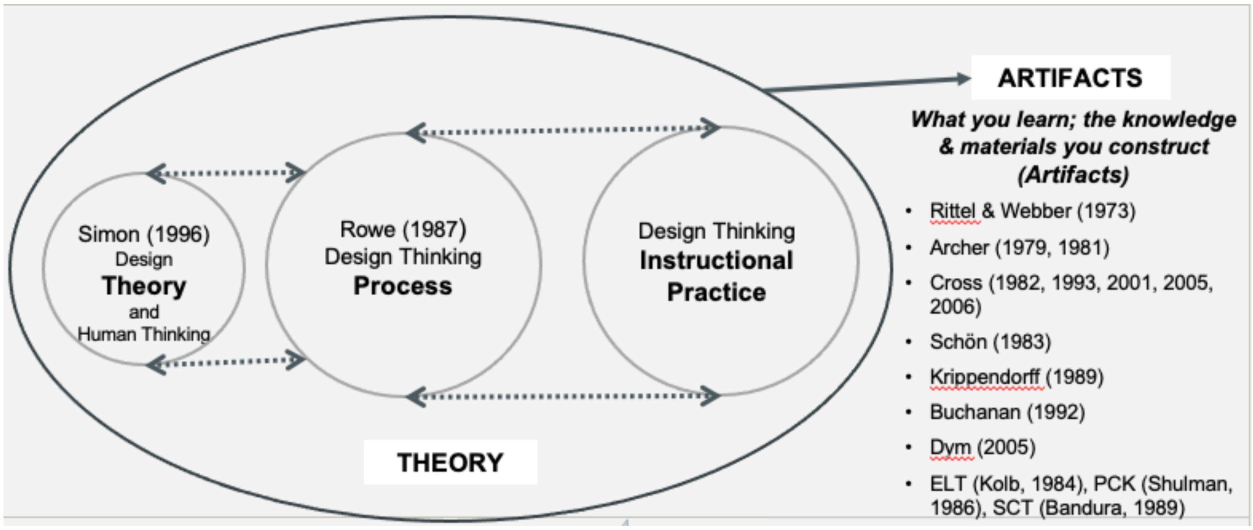
Design thinking knowledge construction resides at the high intellectual level of the human-made world - the artifacts that represent and formulate knowledge constructed to satisfy human needs. Examples of human-made artifacts include: education, STEM, architecture, business, medicine, pharmaceuticals, housing, food, clothing, transportation, space travel, music, entertainment, trinkets, gaming, the world clock, and mono-, multi-, and trans-disciplinary pedagogy. Many believe that the wide use of design thinking contributes to fragmented understandings that stem from the lack of a single definition, varying characteristics, or the underlying discourse regarding different processes (Dorst, 2006, 2010, 2011; Kimbell, 2011; Owen, 2007).

Design thinking knowledge construction artifacts are useful in curricula, domain expertise, and emerging pedagogical content knowledge. Design thinking knowledge construction enhances the student's ability to choose between different academic paths and career options and for creating knowledge for different personal interest paths (Anderson, 2012, p. 43). The design thinking instructional practice descriptive model is a tool that synthesizes research findings on effective knowledge growth from emergent content knowledge for instructional practice. Crossing the line of once narrowly scoped discipline-specific worldviews to multidisciplinary content integration describes the more complex and analytical skills required of educators. They “must not only be capable of defining for students the accepted truths in a domain. They must be able to explain why a particular (new) proposition is deemed worth knowing, how it relates to other propositions, both within the discipline and without, both in theory and in practice” (Shulman, 1986, p. 9).

The design thinking knowledge construction descriptive model benefits teaching and learning approaches that must often go beyond the teacher’s domain expertise. Curriculum development of this nature requires multidisciplinary content knowledge and instruction of students whose domain interests demonstrate and advance learning beyond the educator’s disciplinary boundaries. A transdisciplinary topic, such as *The Case For The Green New Deal* (Pettifor, 2019), is an example of instructional content and context that crosses disciplinary boundaries. In this example, it is desirable to attain a “common core of knowledge that can be shared by the members of all cultures” (Simon, 1996, p. 136). A course focused on the Green New Deal incorporates real-world problems and “transcends the narrow scope of disciplinary world views through overarching synthesis” (Gibbs, 2015, p. 24). This example crosses discipline boundaries to engage learning in more complex, messy, challenges of real-world situations because world problems are no longer well defined.

This need addresses educators’ knowledge growth for desired emergent information resources. A coherent descriptive model highlights the knowledge construction proposition of design thinking theory, process, and instructional practice for emergent content knowledge and discovery learning in a complex and fast changing world. See Figure 4.

Figure 4. Design Thinking Instructional Practice: Theory to Artifacts
(Banks-Hunt, J., 2020)



Recommendations

Technology and information resources are influencing classrooms and content knowledge traditions. Emerging content knowledge is expanding accepted domain subject-matter truths about "what to teach, why it is worth knowing, and how it relates to other propositions both in theory and practice" (Shulman, 1986, p. 8). A design thinking knowledge construction descriptive model is useful for subject matter transformed from the teacher's knowledge of lessons taught into instruction of emergent content knowledge.

Educators tasked with preparing students for the world they enter after graduation are influenced by the need for emergent content knowledge. The descriptive model is a tool that provides a promising way to close knowledge gaps encumbered by rapidly changing resources, technology, highly competitive expectations, and emergent content knowledge propositions. The model provides strategies in a coherent form, making recall and retrieval easier.

Many educators are embedding design thinking attributes in problem-based learning, engineering design, technology education, pedagogical content knowledge, and other experiential learning contexts across a wide range of disciplines. Some seek a single definition for what design thinking is and others claim it allows the learner to escape reliance on rote learning for advancement of open-ended problem solving. And still others suggest that design thinking elevates learning, allowing students to make meaning on their own, think critically, and identify changing human needs. It is challenging for educators to balance emerging content knowledge along with student learning standards, research on teaching, and many learning community activities and expectations. Embedding design thinking attributes in many forms of problem-based learning and experiential learning activities exist across a range of disciplines.

Design thinking knowledge construction has emerged in many forms to allow students to make meaning on their own when tackling emergent content knowledge, such as open-ended, real-world problem challenges. Creation of artifacts or artifacts of constructed knowledge for solving complex problems is one of the earliest topics grounded in design and design thinking literature (Rowe, 1987; Simon, 1969). According to Simon (1996), "Everyone designs." He supported this theoretical proposition for the broad use of design and firmly emphasized that "the intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patent or the one that devises a new sales plan" (p. 111). Simon's pioneering work inspired other theorists and researchers. Johansson-Sköldberg et al. (2013) build on this theoretical proposition when affirming that "the designerly part of the [design thinking] discourse forms an academic stream, with contributions from both designers and related disciplines" (p. 124). According to Koh et al., (2015), "design thinking is treated as a broad concept that encompasses the kinds of thinking that occur in taking the design approach to deal with real-world problems or challenges" (p.2). As educators learn from emergent content knowledge, they gain insight into what their students really need to know. Knowledge construction for learning emergent content knowledge, whether formally or informally, requires educators to step outside teaching as usual to think and act on teaching responsibly and creatively (Marsick, 1998). Design and designerly thinking provide insights for what students really need to know in complex problem-solving lesson plans.

Design thinking knowledge construction is also influencing emergent content knowledge. It provides artifact making to create (a) pathways from fuzzy or abstract understanding of emergent content knowledge, and (b) more concrete attainment of emergent content knowledge growth. The pathways provide knowledge growth in the learner's awareness and evidence of advancing clarity and meaning making. The pathways are active learning experiences that require the learner to engage in meaningful learning activities and to reflect, iterate, refine, and initiate new starting points for designing and making artifacts of learning outcomes.

The design thinking learner engages in many episodes of thinking and learning-by-doing activities. The episodes are cognitive tasks ranging from simple to complex. The cognitive tasks are experiences in the context of an immersive discovery-learning environment. Meaning making is constructed in discovery-learning environments and related events involving (a) reflective practices, (b) willingness to ask questions, (c) conscientiousness to document episodic learning, and (d) appreciation for feedback loops and iteration. Effectively, the practice of design thinking knowledge construction introduces supplementary content for educators' pedagogical content.

A design thinking knowledge construction descriptive model is a tool that benefits educators' representation and formulation of emergent content knowledge and open-ended, real-world problems in instructional practice. The descriptive model shown in previous diagrams provides an internal environment, external environment, and interface for creation of knowledge artifacts. The internal environment is a system for the design process of design thinking. The external environment is the "cocoon of knowledge" for accessing knowledge construction of intellectual activity resources useful for enrichment of the design thinking active learning system. And the interface is a hub for the knowledge artifacts that represents problems and formulates learning things "already known to others from learning things that are new to the world" (Simon, 1996, p. 105).

In conclusion, a descriptive model is a tool that organizes a collection of design thinking theories grounded in the literature. It suggests a body of knowledge for educators and all learners for navigating emergent real-world problems and progressions of content knowledge worth knowing.

> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice. (Shulman, 1986, p. 9)

A design thinking knowledge construction descriptive model is a tool intended for educators whose rationale for instructional content embraces theoretical propositions worth knowing in the domain subject matter.

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Table 1. Herbert Simon's Theoretical Contributions (1969, 1996).

Design Thinking Literature Review	
Herbert Simon (1969) ***"The Science of The Artificial"*** **Seminal Thinker**	
Theory of Human Thinking	RATIONAL PROCESS • ANALYSIS of Information • Defining the problem (end goals) • Building on prior knowledge • "Reference to cognitive skill of human beings" (p. 75)
Process of Design	INTELLECTUAL ACTIVITY • ACTIVE LEARNING • SYNTHESIS • How to design and make artifacts of transformative learning • "Cognitive tasks ranging from complex to simple ones" (p. 59) • Alternatives of Action (satisficing, good enough (p. 27-29, 119) • Experiments are "strategies in the task that can be learned & discovered while performing the task" (p. 62_
Theory of Evaluation **Utility Theory** **Theory of Structure & Design Organization**	ACADEMIC RESPECTABILITY • "Subject matter that is intellectually tough, analytic, formalizable, and teachable" (p. 112) • Meaningfulness "character of human thinking, how to adapts itself through individual learning, social transmission of knowledge to the requirements of the task" (p. 76)
Theory of Design	COMMUNICATION • "Broadening the capabilities, drawing upon the tools of [knowledge] artifacts" (p. 114) • Design alternatives or outcomes of the satisficing methods "that look for good or satisfactory solutions instead of optimal ones…. useful in a constructive sense but must be synthesized" (pp. 119, 121). • Learning is "any change that produces capacity for understanding problems in new task domains" (p. 100)

Table 2. Peter Rowe's Theoretical Contributions (1987).

<table>
<tr><th colspan="2">Design Thinking Literature Review</th></tr>
<tr><td colspan="2">Peter Rowe (1987)
“Design Thinking”
Terminology Pioneer and Circular Model</td></tr>
<tr><td>Analysis</td><td>NATURE OF DESIGN THINKING
• Defining the problem (clear definition)
• Human Thinking
- Exploring possibilities (needs, revelations)
- Major ideas & thoughts
- Making sense of new & unexplored things (abstract or fuzzy ideas)
• Collection of descriptive properties – not one definition
• Intuitive Process</td></tr>
<tr><td>Synthesis</td><td>PROCESS OF DESIGN
• Creative problem-solving activities (construct, modify)
• Big ideas (malleable), disentangling puzzles
• Begin with end goals in mind
• Reflective problem-solving process (circular, iterative)
• Episodic structure is”to and from movement between exploration and evaluations; taking stock of the situation; particular orientation that preoccupies the designer” (p. 34)
• Complex texture of decision making</td></tr>
<tr><td>Evaluation</td><td>ACADEMIC RESPECTABILITY
• Elevate intellectual activity to an academic level
• Pedagogical content knowledge requirements</td></tr>
<tr><td>Communication</td><td>DESIGN THEORY
• Learning outcomes
• Meaning making, concrete knowledge
• Discussion of knowledge constructed artifacts and work-in-progress
• Design theory & process: RECONSTRUCTION</td></tr>
</table>

Manuscript 2

Design Thinking Instructional Practice: Exploring Faculty's Preparation, Context, and Classroom Instruction

Abstract

Design thinking terminology and instructional practice are adopted in many academic disciplines. What can be learned from faculty classroom instruction that engages students in design thinking activity? This paper presents case study findings of undergraduate faculty members' perceptions of design thinking preparation, the learning context, and instructional practice in design-based courses. The study's participants are faculty representing different engineering disciplines at a large, public, research-intensive institution in the southeastern United States. A case study methodology is used in which two exemplars of design thinking for instructional practice are explored. The purpose of this case study is to contribute to a growing research base focused on design thinking pedagogy. Findings suggest that participants' course design, design process, and course management influence students' ability to navigate real-world, open-ended, problems that have no right answers. Because findings are not tied to engineering but rather course design, design process, and course management, the study adds clarity of understanding design thinking for instructional practice useful in a wide range of fields across the academy.

Keywords: design-based course, design thinking, instructional practice

Describing what instructors are doing in a design thinking instructional practice can be as challenging as defining design thinking terminology. A design thinking instructional practice is often associated with design cultures or the design processes in engineering disciplines. Nigel Cross (1982) described design thinking as "its own distinct intellectual culture; its own 'designerly' things to know, ways of knowing them, and ways of finding out about them" (p. 225). Profoundly, design thinking's foundational literature identifies attributes that are justified in instructional practice. The attributes are teachable dimensions of design thinking activity useful for students' development of skills, knowledge, and programs to tackle well-defined and ill-defined types of problems. Design thinking instructional practice engages students in an intellectual culture of design activity to "design problems like the problems or issues or decisions that people are more usually faced with in everyday life" (p. 228).

Design thinking is "justifiably a part of everyone's education" (Cross, 1982, p. 228). The terminology, *design thinking*, emerged as a traditional practice of designers used for problem finding and solving primarily in architecture, engineering, design and art, and European industrial design. Today, it is endorsed by learning models and pedagogy used in design lab/courses at universities, K-12 schools, and non-design cultures and institutions (i.e., politics, social sciences, and design consultancy). Camacho's (2016) description of design schools and design consultancy, the Stanford Hasso Plattner Institute of Design, also known as the "d.school" or "Stanford d.school," and the global design consultancy company, IDEO, are endorsements of models and pedagogy in instructional practice (p. 88). The endorsements by design and non-design cultures broaden the applicability of design thinking terminology, preparation, and instructional practice for traditional designer's practices and teachable schemas beyond design fields. Some researchers believe that a design-based pedagogy facilitates students' interdisciplinary knowledge and improves learned knowledge. Others engage in an ongoing discourse regarding approaches of design thinking instructional practice, such as “designerly” ways of thinking, knowing, communicating, and creating artifacts in problem-solving (Archer, 1979; Cross, 1982; Simon, 1996), and design practice and competence useful for fields within and beyond the traditional design context in practice-based activity (Johansson-Sköldberg et al., 2013; Lawson, 2006; Rowe, 1987). These design thinking debates challenge the instructional practice and preparation needed to facilitate problem finding and solving beyond the boundaries of design cultures (Archer, 1979; Rowe, 1987; Simon, 1996 [1969]). However, instructors facilitating design thinking as constructive, problem-solutions thinking focus on everyday artifacts of knowledge, innovation, health, and happiness reinforces a defensible position that design thinking is for everyone.

Design thinking is more than a concept practiced in design cultures. “Design thinking can transform our actions, enhance our teaching, and provide ways to reshape design’s position within the academy” (Orthel, 2015, p. 1). When facing a problem new to us, the thinking context useful in everyday life for developing a path from problem to solution, is the context of design thinking cognitive activity. Traditionally, design thinking activity is the thinking context of an engineer, medical practitioner, business person, policy maker, writer, young student, and everyone encountering new and often ill-defined problems in our rapidly changing society of information and technology. Simon (1996) noted, “everyone designs, engineers are not the only designers” (p. 111), while Rowe (1987) described the cognitive activity of designers as “the underlying structure and focus of inquiry directly associated with those rather private moments of ‘seeking out’ for the purpose of inventing or creating artifacts” (p. 1). Wrigley and Straker (2017), on the other hand, shifted design thinking from concept to broad educational programs with a focus on multidisciplinary teamwork, exposing students to knowledge and skills outside of their disciplines. These contexts situate design thinking in cognitive activity, whether individual or teamwork, for creating artifacts of skills, knowledge, and educational programs for solving problems.

Design thinking activity is not isolated to design disciplines. The attributes of design identified in Herbert Simon's (1996) thesis on *The Science of Design* predict widespread use of knowing how to design and make artifacts "that have desired properties" (p. 111). Simon claims "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p. 111). Thus, design theory, process, and instructional practice attributes are no different in business, law, medicine, education, sciences, humanities, and all disciplines. Predictably, the theoretical roots of design thinking include design theory, process, and instructional practice attributes for widespread use in design and non-design cultures, because everyone is a design thinker and incorporates design thinking attributes in everyday life.

According to Simon (1996), the theory of design and human thinking, design process, and design practice are attributes of the discovery of solutions to new and/or challenging problems. The theory of design and instruction in design are concerned with organization of a design process to influence valued activities, such as, design tasks, efforts, and "how things ought to be, with devising artifacts to attain goals" (p. 114). Human thinking is the designer's character as it adapts "through individual learning and social transmission of knowledge to the requirements of the task environment" (p. 76). The design process involves the actions (behaviors) of seeking a problem solution. The actions are tasks, efforts, and implementation for "gathering information about problem structure that will ultimately be valued in discovering a problem solution" (p. 127). These attributes of design—theory, process, and instructional practice—have found their way into curricula and play an important role in strengthening education.

Herbert Simon's (1996) design attributes are used across disciplinary boundaries when "creating a design and what takes place while the creation is going on" (p. 137). They have continued to evolve in curricula for discovering problem solutions. Although Simon did not emphasize "design thinking," Peter Rowe's (1987) seminal work, *Design Thinking,* "provides one of the earliest discussions of the concept" (Kimbell, 2011, p. 291). Rowe used design thinking terminology in the context of cognitive activities for discovering problem solutions through a design process of exploring possibilities. Thus, the theory, process, and practice of design attributes created by Herbert Simon (1996) evolved into the attributes of design thinking for creation of artifacts.

At first glance, design thinking attributes appear specific to design and design cultures, especially given the origin of designers' practices in areas of architecture, engineering, design science, and design disciplines dating from the 20th century design methodology movement (Cross, 2007). On the contrary, however, from the early theorists to present day, design thinking attributes align with contributions of educational theorists before and after Herbert Simon's *Science of Design* thesis. The alignment strengthens the utility of design thinking activity across both design and non-design cultures to realize problem finding (discovery) and solving goals in everyday life.

The usefulness of design thinking for finding and solving problems in everyday life is experiencing growth in design cultures and beyond. The growth "is driven in part by a widespread feeling that the intellectual content of design is underestimated" (Dym et al., 2005, p. 104). In a larger part, design thinking has been popularized by its wide use in education, in general, “more and more frequently we hear the term ‘design thinking’ – a concept used both in theory and practice and as a great tool to be used in teaching/learning process” (Luka, 2014, p. 63). Nigel Cross (1982) expressed his belief that there is a missing culture in education that has not been adequately named. He suggests implications of design thinking that are applicable to everyone’s education regarding “what it means to be ‘designerly’ rather than to be ‘scientific’ or ‘artistic’” (Cross, 1982, p. 222).

This case study addresses the paucity of research that describes the attributes of design thinking instructional preparation and practice. It draws from the literature on design thinking in education and perceptions of the study’s faculty participants regarding design thinking instructional preparation and practice. The intent of communicating the study’s research findings is to broaden instructors’ understanding of design thinking instructional preparation and practice in our field of educational psychology.

Literature Review

Many researchers claim design thinking represents different approaches to designing and making artifacts of constructed knowledge as representations of various problem situations and problem solutions (Schön, 1983; Simon, 1996). They claim that design thinking influences contributions to designing ways of knowing emergent subject-matter in an era of rapidly changing information and technology as well as complex problems in which no right answers exist. There are a number of “identified design areas [referred to as] designing, design strategy, and corporate-level design thinking…aligned with the parameters of innovation” (Na et al., 2017, p. 13). The different design thinking approaches create an environment of design actions/activity, such as, designing for the purpose of creating a product, that solves specific problem situated in a subject-matter, domain-specific, cross-disciplinary, or open-ended, real-world problem context.

Many researchers refer to design thinking as the design actions/activity of solving puzzles of problem solving (Buchanan, 1992; Rowe, 1987). Design thinking activity influences innovation, pharmaceuticals, political campaigns and has therefore contributed significantly to academic disciplines across the academy. Awareness of design/design thinking activity projects are a spotlight on design thinking propositions, attributes, and cognitive tasks that are often hidden influences on subject-matter and domain-specific content (Gleasure & Riordan, 2016). "Design thinking may be considered as a great tool to be used in teaching/learning processes to develop twenty-first century skills. It comprises collaboration in order to solve problems by finding and processing information" (Luka, 2014, p. 63). However, describing what instructors are doing in a design thinking activity is challenging because of a the wide-range of applications.

Design Thinking Theoretical Contributions. The literature review explored design thinking with a lens focused on theoretical propositions that provide an understanding of the influence of design on problem representations in the academic realm. Design thinking is comprised of three primary attributes: theory, process, and practice. The attributes are useful for construction of knowledge and artifacts needed to solve problems in everyday life. The literature locates these attributes in a wide range of theoretical contributions and curricula. The theorist to introduce design thinking terminology was Peter Rowe (1987) in his seminal work *Design Thinking*. Rowe synthesized the practices of designers described in the "theory of design" and "curriculum in design" introduced some 18 years earlier by theorist Herbert Simon (1969). In Simon's thesis on the "Science of Design" (Simon, 1996), he discusses the theory and curriculum of design and defines the role of design in the life of the designer's mind. He broadens the definition of the designer to include “any professional whose task is to solve problems, to choose, to synthesis, to decide” (p. 136). According to Simon (1996),” it is possible to organize the instruction [of design] within a framework of systematic formal theory” (p. 135).

Originally, design thinking emerged as the academic practice of designers, such as, architects, engineers, design artists, industrial designers, and urban planners. Today, however, the utility of design thinking has been adopted in a wide range of applications. The growing acceptance of design thinking “is driven in part by a widespread feeling that the intellectual content of design is underestimated” (Dym et al., 2005, p. 104). In a larger part, design thinking has been popularized by a growing number of adoptions in education.

Design thinking adoptions across the academy have increased the interests of educators. This curiosity likely stems from ‘design thinking’ terminology being referenced frequently in teaching/learning pedagogy and is used to describe professional responsibilities focused on solving different types of problems in everyday life, especially ones that are not well-defined (Buchanan, 1992; Luka, 2014; Rittel & Webber, 1973). Simon (1996) described the design process as an “intellectual activity that produces the material artifacts” (p. 111). Material artifacts are knowledge constructions useful for everyday life “produced by art rather than by nature; not genuine or natural, man-made as opposed to natural” (p. 4). Design thinking focused on solving problems and the creation of material artifacts demonstrate observable professional responsibilities that represent the interests of educators in “a considerable number of examples of actual design processes, of many different kinds…[and] tangible record of the variety of [teaching/learning] schemas” (p. 135).

The interest in design thinking was traditionally claimed by designers and practitioners of design-based cultures across the academy. Members of the design culture in academia understand and connect with the problem-solving processes that involve a "variety of cognitive tasks ranging from relatively complex ones…through intermediate…to simple ones that have been favorites of the psychological laboratory (rote learning)" (Simon, 1996, p. 59). Members of the design culture readily contemplate design tasks because of design opportunities inherent in designer's practices that negotiate the path between problem state and solution state (Middleton, 2005; Rowe, 1987). The wide range of design thinking applications in design and non-design cultures prompt rethinking and breaking down boundaries to acknowledge the broad culture of design thinking. But, we're not there yet because there is a lack of understanding about design thinking. As Kimbell (2009), acknowledges, "This lack of understanding comes at a time when the term 'design thinking' has emerged among some scholars, managers, designers and educators, as a way to distinguish between craft skills of designers, and a way of approaching problems" (p. 3). Kimbell's (2011) continued to research and explore ways of approaching problems and emphasized rethinking design thinking. Rethinking considerations address the historical emphasis on the origins of design thinking situated in design cultures and isolation of design across disciplines and cultures in the academy. The researcher expands upon design thinking applications.

Design thinking applications appear in expanded fields and specialty areas. Simon (1996) focused on the principles and cognitive activities of design to explain what it ought to be and its utility for "importing and exporting from one intellectual discipline to another, ideas about how a serially organized information-processing system like a human being—solves problems and achieves goals" (p. 138). Simon claimed that the artifacts of solved problems are created through the process of design; and the process of design is the same intellectual activity whether "prescribing remedies for a sick patient or the one [person] that devises a new sales plan" (p.

101). Therefore, whether in engineering, architecture, business, medicine, politics, or designing a vaccine for COVID-19, the influence of design on problem-solving is the same no matter the discipline.

Approximately 18 years after Simon's influence on principles and cognitive tasks of design and its utility for problem-solving, Rowe (1987) introduced the terminology, design thinking, to explain the intellectual activity or cognitive tasks of designing and making artifacts. By training, Rowe was an architect and developed the concept of design thinking from design practices and traditions of architects. According to Rowe, when problems are open and without known solutions, generating an initial idea is the starting point for ways to approach solving these problem situations. Design thinking is more than terminology, it provides a "creative problem-solving process at work in design by way of the logical structure of overt activities that appears to take place" (Rowe, 1987, p. 46). Design thinking as a creative problem-solving process involves cycling through stages or steps of the design process to construct, test, reflect, and iterate on design ideas and solution prototypes when designing and making artifacts of constructed knowledge (solutions). The ideas are not necessarily correct or incorrect, but are representations of "what is involved in creating a design and what takes place while the creation is going on" (Simon, 1996, p. 137).

The attributes of design/design thinking are grounded in the literature (Rowe, 1987; Simon, 1996), although not in a single theoretical contribution as there have been many contributors. The attributes of design/design thinking "involves using human ability for creative problem solving around ideas, processes, or systems that serve needs" (Henriksen et al., 2017, p. 141). The attributes are the teachable dimensions of design thinking activity useful for finding and solving problems. The attributes - theory, process, and instructional practice - are interconnected. The theory drives process, process drives practice, and practice drives creation of artifacts as problem solving outcomes. Design thinking theory, process, and practice contribute to components of the designer's actions for creating problem-solving design alternatives.

Design/design thinking attributes contribute to designer's actions in the following ways:

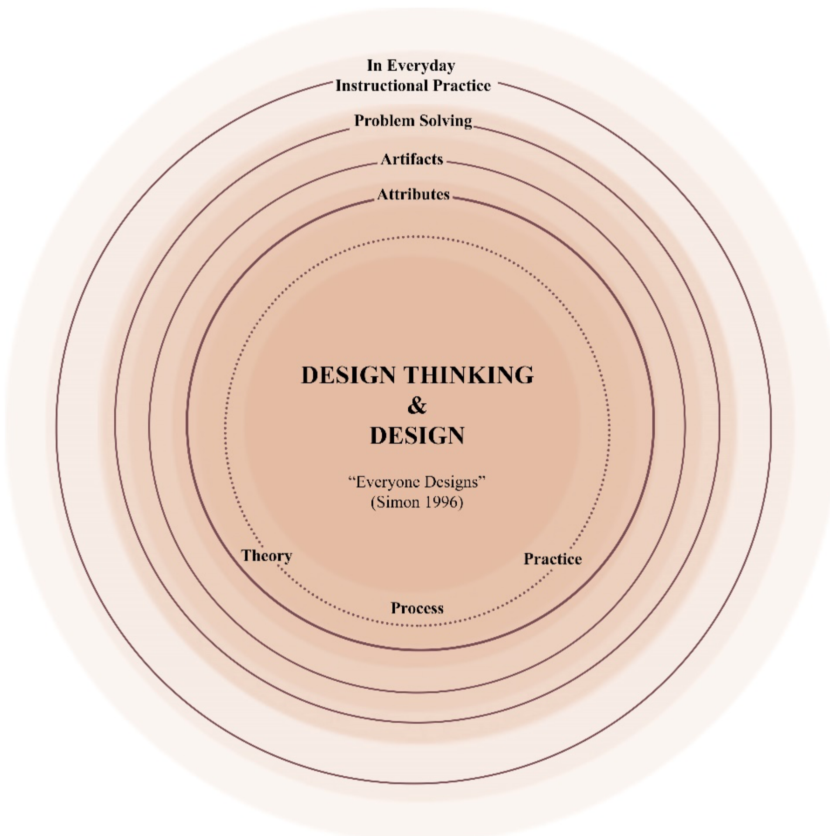
1 Theory: knowledge of what students will learn and how to develop design thinking knowledge, tools, & skills; bridge between process and practice

2 Process: knowledge of how to design and make artifacts, inclusive of knowledge of curriculum materials, defining problems, exploration of ideas, group work, iteration, brainstorming, reflection-on-actions, synthesis, "satisficing," higher-order cognition (analysis, creation, evaluation); nonlinear; bridge between theory and practice.

3 Practice: knowledge of teaching subject matter and design and/or design thinking that interconnects design thinking practice to theory and process; communication of findings and contributions; experience-based knowledge makes formal learning practical.

(See Figure 5)

Figure 5. Design/Design Thinking Attributes Embedded in a Growing Research Base (Banks-Hunt, J., 2020)



Design thinking attributes describe the designer's actions to (a) integrate theoretical dimensions that accounts for and inform the undertaking of constructing knowledge to solve problems, (b) demonstrate experience-based knowledge taught in the hands-on, learning practice, and (c) promote a process of higher-order cognition "involved in creating a design and what takes place while the creation is going on" (Simon, 1996, p. 137). The range of different types of problems, from well-defined to ones that are ill-defined, leverage the design/design thinking attributes to facilitate designerly ways that students solve real-world problems.

Design thinking attributes engage students in intellectual rigor useful for tackling different types of problems. Revisiting Simon's (1996) *theory* of artifact making provides intellectual rigor to enhance design "subject matter that is intellectually tough, analytic, formalizable, and teachable" (p. 112). Rowe's (1987) theoretical contributions remind us that design thinking as *process* of problem-solving provides "the underlying structure and focus of inquiry directly associated with those rather private moments of 'seeking out' for the purpose of inventing or creating artifacts" (p. 1). A number of theorists, researchers, and practitioners, have contributed to the practice of designing and making artifacts of meaning making for problem-solving (Archer, 1979; Krippendorff,1989; Schön, 1983). Krippendorff's (1989) iteration proposition contributed to the problem solver's *practice* of meaning making through repetitions in the design process to refine ideas and learning outcomes. Design process iteration strengthened Schön's (1983) reflective *practice* proposition that focused on reflection-upon-actions to provide problem-solvers both artistic and creative ways to negotiate complex situations. And design schools and consultancies, like IDEO and the Stanford d. school, have contributed non-linear design thinking models to guide rigorous techniques useful for tackling different types of problems.

Design Thinking in Education. Students today are engaged in a variety of subject-matter and/or domain-specific problem situations that are solve using design thinking propositions and activity. Yet, according to Cross (1982), design thinking is an intellectual culture missing in education. There is a definite design culture in academic settings that represent traditional design disciplines. Design thinking applications are not limited to design disciplines and a design thinking culture is less identifiable because of the wide range of design thinking applications in the academic realm. Orthel (2015) positioned design thinking in teaching and learning as a way of preparing students for new or emergent problems. He addressed the thinking context useful in everyday life for developing a path from problem to solution and claimed, "design thinking can transform our actions, enhance our teaching, and provide ways to reshape design's position within the academy" (p. 1). According to Lin et al. (2019), design thinking enables students' learning outcomes by designing projects in a tangible learning process using constructivist teaching and learning approaches. Noweski et al. (2012) proposed giving space to students to try out different methods, such as designing projects, that apply "abstract and general principles (instructions) in meaningful and responsible actions in life (construction)" (p. 78). Koh et al. (2015) supported an educational landscape in which "design thinking has the potential to contribute to the development of the creative and adaptive capacities of students, thus enabling them to acquire the knowledge, skills, and attributes needed for collaborative problem solving of complex problems" (pp. 8-9). Additionally, Wrigley and Straker (2017) shifted design thinking from concept to broad educational programs with a focus on multidisciplinary teamwork, exposing students to knowledge and skills outside of their disciplines. These contexts situate design thinking in intellectual rigor useful for tackling different types of problems, without reference to design or non-design cultures, in the design process of individuals and teams focused on creating artifacts of constructed knowledge useful for solving problems.

The intellectual rigor of lessons that are taught to students using rote learning methods and lessons taught using a method called "learning with understanding" differ (Simon, 1996, p. 101). The method, learning with understanding, is a cognitive tool that differs from rote learning. It was Simon's perspective that teaching a lesson using rote learning methods expects prescribed solutions for subject-matter problems that "can be regurgitated more or less literally, but it cannot be used as a cognitive tool" (p. 101). He further states that there exists a distinction between rote learning methods and learning with understanding methods - but the difference is "not thoroughly understood" (p. 101). Yet, Simon also claimed that "every teacher knows there is a profound difference between a student learning a lesson by rote and learning it with understanding, or meaningfully" (p. 101). Theoretical contributions grounded in the literature support the differences between the intellectual rigor of lessons taught using rote learning versus learning with understanding in which "there is thus no 'right' or 'wrong' solution, only 'better' or 'worse" (Rittel & Webbber, 1973).

The nature of meaningful learning is different from problem solving in a rote learning context. Problem-solving in a rote learning context may test the student's skill level to solve problems from the textbook with modified parameters. Students are expected to demonstrate solution modifications for modified parameters of known problems. However, in a global society of rapidly changing information and technology, where many of the challenging problems are not in textbooks, meaningful learning thrives. When problems are situated outside the textbook, such as, real-world problems, meaningful learning techniques are observable, tangible records of problem solving. An example of meaningful learning in design cultures is the well-known approach, 'designerly' ways of knowing, suggested in teaching/learning approaches that provide methods of knowing how to design and create artifacts of constructed knowledge for meaning making (Krippendorff, 1989; Schön, 1983).

Bruce Archer (1979), a professor of design research and theorist, contributed the problem solving proposition "that there exists a 'designerly' way of thinking and communicating that is both different from scientific and scholarly ways of thinking and communicating and as powerful as scientific and scholarly methods of enquiry, when applied to its own kinds of problems" (p. 17). "Designerly" ways of thinking and communicating provide effective ways of knowing “most of the problems that most people face most of the time in everyday life” (p.17). Cross (1982) revisited Archer’s theoretical proposition claiming that it is the process of designerly ways knowing that are applicable to everyone’s education. Cross believed designerly ways of knowing were teachable schemas and provided the designer/problem solver “things to know, ways of knowing them, and ways of finding out about them” (p. 221). The theoretical contribution of Archer and Cross reinforce design-based methods of solving everyday life problems [i.e., real-world problems] and “what it means to be ‘designerly’ rather than to be ‘scientific’ or ‘artistic’” (p. 222).

Schön (1983) added reflective practices to enrich designerly ways of knowing with the theoretical contribution of artistic and creative ways of negotiating complex situations. Schön’s reflection-upon-actions formalized constructionism, a major contribution to the field of designing and making artifacts of knowledge, at every stage of the design process. Krippendorff (1989) focused on the creation of meaning making in artifacts to cognitively construct meanings and refine meaning making through iteration. Buchanan (1992) added design process tools to visually situate design ideas in an appropriate problem space: drawings, sketches, brainstorming, prototyping, simulations, etc.). These theoretical contributions gave the design process its circular topology for creation of artifacts through reflective actions at every stage, negotiating complex situations, and cognitively constructing learning with understanding, or meaningfully. Kolb’s (1984) experiential learning theory (ELT), is a way of characterizing the experiments in the design process useful for testing design ideas and reflecting upon outcomes or material artifacts of constructed knowledge. Overall, the intellectual rigor of design/design thinking lessons comprise combinations and arrangements of cognitive tools for knowing how to design and make artifacts of constructed knowledge based on a collection of theoretical contributions.

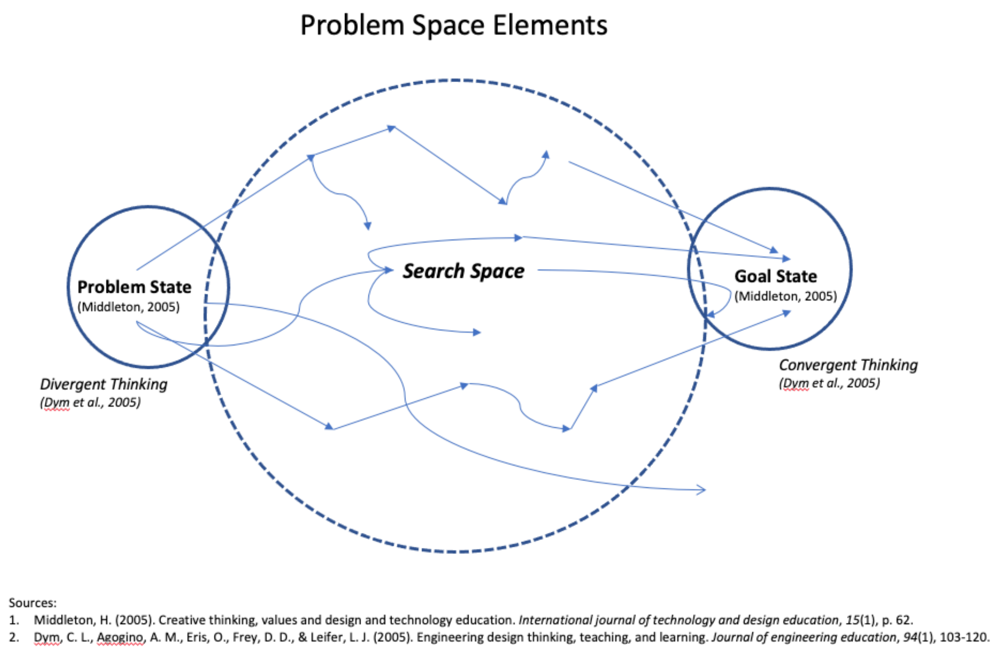
"Designerly" Ways of Knowing, Thinking, and Communicating. Design thinking is a collection of theoretical contributions. Instances of elements in the collection of theoretical contributions exist in a wide range of applications to reinforce a design process for "designerly" ways of knowing in problem-solving that involves learning with understanding, meaningfully. "Designerly" ways of thinking, knowing, and communicating, grounded in the literature, are rigorous design thinking approaches comprising "the ideas which govern the nature of every sort of artefact produced, used and valued by man" (Archer, 1979, p. 19). Design thinking ideas offer the flexibility to design and make solutions that address problem situations that supersede rote learning, especially when the content is not textbook-based. It is for learning with understanding and navigates a wide range of complex problem situations, such as open-ended, real-world problems.

> Design thinking has a multi-/interdisciplinary character. The problem-solving process frequently involves drawings or sketches but also the making and use of models, simulations, and prototypes. These tools are useful for external representations of thinking to reduce cognitive load. In addition, they provide alternative paths experiential learning" (Koh et al., 2015, p. 3).

Buchanan's (1992) theoretical contributions to learning with understanding also emphasize tools useful for visualizing problem-solving for learning with understanding (drawings, sketches, prototypes, simulations, etc.) as discussed above by Koh et al. (2015). Simon (1996) also contributed to the discussion on learning with understanding in his elaboration of design theory and curriculum and the role of design in the life of the designer's mind. He broadened the definition of the designer to include "any professional whose task is to solve problems, to choose, to synthesis, to decide" (p. 136). According to Simon (1996)," it is possible to organize the instruction [of design] within a framework of systematic formal theory" (p. 135). Examples of a framework of systematic formal theory include (a) design theory and practice in design standards such as Engineering Education in Science (Moore et al., 2014; NRC, 2015) or Accreditation Board for Engineering and Technology, Inc. (abet.org, 2019), (b) design thinking activities in design process, and (c) design thinking instructional practice examples in models, such as, problem-based leaning (PBL) (Wood, 2003), the PIRPOSAL model (Wells, 2016), Design Competency Model (Razzouk & Shute, 2012; Shute & Torres, 2012), and/or the Five Stages of the Design Thinking Process proposed by the Hasso-Plattner Institute of Design at Stanford (d.school), and other models for education (Dorst, 2010; Jobst et al., 2010; Plattner et al., 2015; Savery & Duffy, 1995; Scheer et al., 2012). These endorsements demonstrate a broadened applicability of systematic theory useful for teachable schemas of design thinking instructional practice to address design and human problem solving for achievement of desired solution(s).

Howard Middleton (2005) characterized design and human problem solving in a visually succinct, problem space diagram, unlike human problem-solving strategies that contain "checkpoints for evaluation of progress, many feedback loops, many branches, many iterations" (Newell & Simon, 1972, p. 146). Middleton's problem space diagram visually replicates the design process and path to desired solution(s) as two parallel paths of three simple elements: (a) problem state, (b) goal state, and (c) search pathway. The problem state is where the problem solver starts problem solving and the goal state is the ending point, the solution. The third element is the bridge-like search pathway that exists between problem and goal states. The bridge symbolizes the problem-solver's journey across accessible and related information leading to the problem solution. Visually, two of the three elements of Middleton's problem space duplicate Dym's (2005) theory of divergent and convergent thinking. When overlaying Dym's symbolisms for divergent thinking ("less than" symbol in mathematics) and convergent thinking ("greater than" symbol in mathematics), it is possible connect to other theoretical propositions in the design thinking problem space. Middleton discusses the implications of the problem space to provide a "process to use in design and technology programs in schools" (Newell & Simon, 1972, p. 62). His discussion applies the concept of design process stages or steps of the design process, discussed by other theorists and researchers, to the progression from problem identification (problem state) to solution evaluation (goal state; see Figure 6).

Figure 6. Problem Space Model



Today, design thinking is endorsed by a wide variety of learning models and pedagogy used in design lab/courses at universities, K-12 schools, and non-design cultures and institutions (i.e., politics, social sciences, and design consultancy). Camacho's (2016) description of design schools and design consultancy, the Stanford Hasso Plattner Institute of Design, also known as the "d.school" or "Stanford d.school," and the global design consultancy company, IDEO, are endorsements of models and pedagogy in practice (p. 88). The endorsements by design and non-design cultures broaden the applicability of design thinking in academic settings. Instructors facilitate design thinking as constructive, designerly ways of thinking, knowing, and communicating in a wide range of academic settings in which students construct material artifacts of knowledge. These constructions involve design thinking intellectual activity (theory), the design process activity of designing and making material artifacts of knowledge (process), and design thinking methods, such as designerly ways of knowing and learning with understanding (instructional practice).

Design thinking is "a way of approaching problems supposedly common to designers that might be adopted" across academic and business realms (Kimbell, 2009, p. 3). Design thinking adoptions beyond design fields provides a growing understanding of design thinking and related teachable schemas in a spectrum of academic settings to explore problem solving by constructing material artifacts of knowledge (Kimbell, 2009; Simon, 1996). Theoretical contributions, problem space diagram, and models in education, from simple to complex problems, comprise a collection of elements that have been presented one at a time as descriptive constructs or propositions of design thinking. "Although we often present propositions one at a time, we recognize that they are better understood if they are organized in some coherent form…otherwise they become terribly difficult to recall or retrieve" (Shulman, 1986, p. 11). This comment raises the question: What are instructors doing when teaching students problem-solving using design thinking approaches?

The concept, design thinking instructional practice, or what instructors are doing when teaching with embedded design thinking approaches in the pedagogy, is less prominent in the literature. Rowe (1987) suggested "A useful way to begin the development of design thinking is by looking at some actual examples of designers at work" (p.2). Simon (1996) supported learning from examples to engage in "the idea of learning from examples can be extended to a method of learning 'by doing… to make artifacts that have desired properties and how to design'" (pp. 105, 111). The article's case study explores two faculty participants' perceptions and practice of design thinking attributes informing their instructional practice in design-based courses. The current case study explores two faculty participants' perceptions and practice of design thinking attributes informing their instructional practice in design-based courses. The findings of the study communicate rich, descriptions of design thinking instructional practice for the field of education curriculum and instruction. Overall, the study provides examples that address the paucity of research focused on design thinking instructional practice.

Methodology

This study was guided by the overriding research question: "What can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity?" This purpose was addressed through two main research questions:

> RQ1. How are faculty participants' perceptions of developing and implementing design-based courses informing "designerly" ways of instructional practice?
>
> RQ2. How do faculty perceive that their instructional practices engage students in design thinking activities?

These research questions were answered through analyses of evidence attained through interviews and course documents (syllabi, schedule of assignments, course websites, etc.) of two faculty members currently engaged in teaching design-based course.

Academic Context. Design thinking instructional practice in this article is situated in a research-intensive, large public, undergraduate, university in the southeastern region of the United States. The participants are faculty members of traditional design engineering disciplines, although not in the same department of engineering. The faculty participants in the case study have demonstrated teachable schemas or instructional approaches in design-based classes for more than 20 years. Each participant embeds design thinking activities in engineering senior design capstone courses. The participants expose students to open-ended problems that provide realistic exposure to real problems that do not have right answers. The participant's perceptions of preparation and practice were probed to understand instructional practice in design-based classes. They supported student learning objectives and achievement strategies inclusive of skills and design-based theory and practice, design process, design thinking activities, and course management tools, useful for tackling different types of problems —well-defined and ill-defined.

Design thinking instructional practice is a pedagogical approach that has gained significant attention across the academy because it is "meant to encompass everything good about designerly practices" (Kimbell, 2011, p. 289). The literature about *designedly practices* situates the concept and "development of design in general education" (Cross, 1982, p. 222). A design thinking pedagogy is a popular trend useful for adopting design thinking in problem-centered curricula. "The eagerness to adopt and apply these design [thinking] practices in other fields has created a sudden demand for clear and definite knowledge about design thinking" (Dorst, 2011, p. 521). The study contributes to a growing research base focused on design thinking instructional practice and other gaps related to what instructors are doing in design-based courses, such as, the preparation and practice suggested for student engagement.

Because of design thinking research and instructional practice, utility of this domain has shifted from being narrowly situated in the traditional practices of designers toward real world or contemporary applications. Designers and non-designers in a wide range of applications engage in a process of evaluation and synthesis of contemporary problems in the real world. When real world problems are outside the textbook, learning outcomes are not based on traditional textbook, rote learning approaches to learning, but rather, learning meaningfully, from realistic, real-world, experiences.

Participants. This case study was an exploration of faculty's perceptions of design thinking instructional preparation and practice. The study investigated faculty participants' perceptions regarding design thinking instructional preparation and practice in a design-based course setting. The study involved two faculty members teaching senior design-based capstone courses.

Senior design capstone courses satisfy one of the undergraduate engineering graduation requirements at the participants' research-intensive university. Projects were formulated by the faculty participants and/or industry-sponsored partnerships, and all projects mirrored real world engineering design problems in traditional engineering design cultures.

The study's faculty participants represented a selected, small, purposive sample of two professors who are teaching senior capstone courses. They are from different disciplines of the research institution's engineering design culture. As research study volunteers they received no compensation for their participation. The study's faculty participants were given pseudonyms, Virginia and Elliott, to protect their identity.

Virginia. Virginia holds a BS in Mechanical Engineering from a large public, research, university in the southeast. After graduation, she worked in industry for 20 years and much of that time was spent in project management roles for engineering projects. At the time of the study, she had more than 5 years of experience teaching an undergraduate engineering capstone course. Prior to joining the undergraduate faculty, she frequently volunteered to judge engineering capstone design-based projects for the same course that she is now teaching as a Professor of Practice. Her multi-decade industry career experience coupled with many years spent developing relationships with undergraduate design-based course faculty provided course design, design process, and course management skills. Virginia's experience provided an understanding of real-world engineering problems, research, teamwork-building, iterating on the product design process, creativity, divergent and convergent thinking, project management, hands-on experiential learning, communication (both written and orally), working with students, and cultivating industry partnerships. This background advanced Virginia's design-based course preparation and instructional practice. It provided students a more realistic exposure to solving real-world problems sponsored either by industry partners or departmental faculty, teamwork, design process iteration, and thinking-outside-the-box.

Elliott. Elliott holds an engineering Ph.D. degree, Professional Engineer (PE) License, and over 15 years of experience teaching design-based, as well as, traditional domain-specific courses that are non-design-based at the higher education level. Elliott did not have industry experience per se prior to becoming a university faculty member. The majority of his multi-decade career in higher education had been spent as the instructor of the senior design-based capstone course. His preparation included: (a) a Ph.D. in a traditional discipline of the design culture, (b) PE license, (c) consulting and engineering short-term experiences in a small business, and (d) interest in design established before coming to the university as the developer of an Applied Creativity course. Elliott's experiences provided an understanding of good engineering problems in the real-world, research, teamwork-building, iterating on the product design process, creativity, divergent and convergent thinking, project management, hands-on experiential learning, communication (both written and orally), and working with students. This background advanced Elliot's design-based course preparation and instructional practice. It provided students a more realistic exposure to solving good problems like those in the real-world, teamwork, design process iteration, and thinking-outside-the-box to solve real-world problems.

Virginia's Course. Virginia's course, Engineering Design and Project Capstone, is taught to undergraduates in their senior year. It was taught as a traditional, large lecture-style course. The class period was 75-minutes in length and was comprised of over 400 students. Since she began teaching the course, she increased the number of industry-sponsored project teams, as well as, opportunities for all teams to interface with real-world engineering teams and/or departmental faculty. Approximately half of the team projects were industry-sponsored, and the remaining ones, departmental-sponsored. All projects offer realistic, real-world, research and product design focused on real-world problems. Virginia's course description states:

> Team oriented, open-ended, multi-disciplinary design projects focused on industrially relevant problems. A specific, complex engineering design problem taken from problem definition to product realization and testing. Emphasis on documenting and reporting technical work. Making informed judgments which must consider the

> impact of engineering solutions in global, economic, environmental, and societal contexts.

Virginia's students were responsible for a specific, complex engineering design problem that is to be taken from the problem state to solution state. This involved the problem development process of multiple stages useful for understanding the problem state and bridging this understanding to the solution state. The design process involved homework assignments whereby students worked in teams to collaborate and communicate technical ideas; analysis approach (problem identification, idea generation and concept selection); design process (application of design and making project artifacts, test, and iteration); and evaluation of outcomes (ethical and professional responsibilities; verification and validation).

Elliott's Course. Elliott's course, Comprehensive Design Project, is also a senior design capstone course taught in an engineering department. The class period was 75-minutes in length and there were 2 sections of 36 students. He taught in a lecture-style classroom setting. Students were seated in consecutive rows of trestle tables with fixed table legs and moveable chairs that were not on casters. Therefore, students did not have the flexibility to rearrange tables from linear rows to other seating configurations. Elliott's course description was as follows:

> Identify and develop an engineering design project using the team approach; use literature resources to define project objectives and approach; present project proposal in a professionally written and oral manner; examine engineering ethics, professionalism, and contemporary issues.

Elliott's comprehensive design project course was team-based and students worked together in small groups of seven or fewer team members. Students self-selected teamwork projects based on topic interests from a list of department-sponsored projects. Project teams engaged in a product design process of multiple stages. Comprehensively, the stages of the product design process provided a systemic approach to designing and making knowledge and material artifacts. The artifacts of the design process represented the design results or student learning outcomes of the comprehensive design project.

In comparing Virginia and Elliott's courses, it was clear that there were similarities and differences. Similarities included: (a) the senior design capstone course is taught over 2 consecutive semesters (in this case, Fall 2019 and Spring 2020), (b) class session length of 75-minutes, (c) the classroom included a central podium, (d) multiple large projection screens were positioned for viewing of lecture slides from around the classroom, (e) students completed project-oriented assignments in collaboration teams, (f) project-oriented assignments are developed by faculty participants and/or university-to-industry partners, (g) multiple white boards positioned for handwritten instruction and course notes around the classroom, and (h) students are undergraduates in their senior year.

Differences included: (a) one of the faculty participants teaches a large section of 416 students and the other taught two sections of 36 students, (b) seating is stadium-style for students of the large class and long, parallel, rows of stationary tables and moveable chairs for students participating in the two-section course, (c) one of the capstone courses required teamwork meetings conducted in a boardroom-style setting, outside of class time, and incorporated industry partners via Zoom meeting technology; and the other conducted in-class teamwork meetings, every class period and teams met in the fixed linear rows of the classroom setting, and (d) one of the faculty participants taught biological systems engineering students and the other taught mechanical engineering students.

Procedure. The empirical research consisted of two phases. The first phase involved one-on-one interviews with the study's faculty participants. The second phase, the data analyses process, used multiple types of data to compare the faculty participants' subjective understandings of design-based instructional preparation and practice. In order to assess what can be learned from faculty perceptions of design-based instructional preparation and practice with regard to engagement of students in design thinking activities, the study implemented triangulation of two semi-structured interviews and document content analyses.

Data Collection

The study's data collection sources included two semi-structured interviews, course documents and resource materials (i.e., syllabi, lesson plans, slides, assignments, and handouts), and a demographics survey. In addition, the researcher observed one class section for each participant. The classroom observation was not data collection, per se, but rather, designed to provide practice-based context for the researcher to embed practice-based questions in the semi-structured interview #2. The documentation collection and semi-structured interviews supported a process of triangulation for more credible, consistent, and complete data from which to develop findings (Creswell, 2009; Creswell & Miller, 2000). Table 3 relates research questions to data sources.

Data collection sources included a demographics survey (pre-study), interviews, and course documents (during study). Faculty participants completed a demographics survey before meeting with the researcher; participated in two, 90-minute, semi-structured interviews; granted the researcher permission to visit the classroom for an observation; and shared course documents. First, faculty participants completed the demographics survey before meeting with the researcher. The survey captured two types of data: (a) faculty participants' background information and (b) the type of design-based course taught (subject domain, prerequisites, enrollment size, and students' higher education level; see Appendix B). Second, faculty participants were interviewed, one-on-one by the researcher. Interviews were recorded and transcribed for open coding. To enhance the interviewing process, the researcher was given permission by the faculty participants to participate in an unobtrusive and non-participatory classroom observation. The classroom observation provided the researcher with practice-based context that included the classroom setting and in-class course-based activity. Third, documents provided by faculty participants were analyzed using summative content analysis. Document content analysis data were comprised of course syllabi, lesson plans, slides, assignments, handouts, and course websites. Lastly, the researcher triangulated the three types of qualitative data collected.

Demographics. The demographics data identified the faculty participants' appropriateness for the design thinking instructional practice descriptive study. A recruitment email letter was sent to roughly 16 qualified faculty members teaching courses in the design culture of the research-intensive university. These qualified faculty members were identified by searching keywords related to the descriptive study before asking about their willingness to participate in the study. An online faculty demographics survey link was attached to the recruitment email. The demographics survey gathered background information that included, gender, ethnicity, age, years teaching overall, years teaching design-based courses, type of design-based course, and teaching background.

The recruitment email sent to prospective faculty participants was a general request to participate in a design-based instructional practice research study - anonymously, voluntarily, and non-incentivized (no compensation; see Appendix A). Ultimately, two faculty members were chosen from 7 respondents based on the type of design-based course (capstone), number of days per week the courses met (one day per week), length of class period (75-minutes), and students' academic level in higher education (senior-level course). As an IRB-approved requirement of privacy, faculty participants were given the pseudonyms, Virginia and Elliott (see Appendix E).

Interviews. According to Creswell and Poth (2016), an interview-based data collection procedure, such as, semi-structured interviews, is "aimed at gathering good information from study participants to answer the research questions" (p. 118). There were two semi-structured interview guides developed for the study. The interview guides provided probing questions focused on the faculty participants' perceptions of design-based course preparation and practice. The semi-structured interviews allowed more freedom for the researcher to arrange questions that were open-ended enough to gather rich, information about design thinking instructional preparation and practice.

The format of each semi-structured interview involved a 90-minute, recorded, informal, one-on-one, face-to-face meeting. At the time, all interviews were conducted in a one-on-one Zoom meeting room because of COVID-19 restrictions in enforcement. All interviews were transcribed within a period of two weeks.

The purpose of Interview #1, was to gain an understanding of the faculty participant's *Perceptions of Preparation and Practice* in a design-based course. The classroom observation followed interview #1 (see Appendix C). The purpose of the observation, as already discussed, was to enrich questions related to the faculty participant's reflections on the instructional practice. In this way, the researcher gained firsthand experiences of the participant's design-based course environment useful for practice-based questions in interview #2. The purpose of

Interview #2, was to gain an understanding of the faculty participant's *Reflections on Practice* (see Appendix D).

Documents. The type of document content incorporated in the study as additional data sources included the participants' course materials: (a) syllabi, (b) course schedules, and (c) PowerPoint lecture notes; other content such as, course websites and videos, were also reviewed. The course material documents provided a comprehensive, compilation of content delivering design-based course materials to students because a textbook was not used. "Observations, interviews, and reviews of pertinent documents, such as the department's publications…highlight the potential value of case studies as an important part of the researcher's full methodological repertoire" (Yin, 2012, p. 144). Yin argued for using methodology in qualitative research for triangulation of data sources to build a strong case study in its complexity and entirety and improve the study's internal validity.

Data Analysis

After semi-structured interviews were recorded and transcribed, they were analyzed using open coding, axial coding, and memo writing techniques. The research focused on providing clarity of understanding the faculty participants' perceptions of design thinking instructional preparation and practice.

Open Coding. Saldaña (2015) divides coding into two major stages: first cycle and second cycle coding. In this study, data were collected in two phases. Phase one involved the first of two, 90-minute, recorded and transcribed, one-on-one, semi-structured interviews. The first interviews probed faculty participants perceptions of design-based instructional preparation. After first interviews with faculty participants, open coding was used to explore, line-by-line, the contents of data collected. In this initial coding or first cycle coding, the interview data collected was explored for possible directions the findings could take.

The first cycle codes were the initial codes or open codes used in the analysis of the transcribed interview data. To assign initial codes, the qualitative data collected was examined line-by-line. These line-by-line discreet parts were assigned descriptive words or short phrases. A team of coders (researcher and two second coders) was used to sharpen the coding process. The coding team consisted of three members, the researcher and two second coders. The second coders did not have similar academic backgrounds to one another or the researcher and were not engineers by training. The two, independent second coders provided cross-checking for the researcher's codes. This arrangement ensured intercoder agreement when "comparing results that were independently derived" (Creswell, 2009, p. 190). Additionally, the coding team established the goal for the coding process with the understanding that "intercoder agreement should be within the 85% to 90% range, depending on the size and range of the coding scheme" (Miles and Huberman, 2020, p. 79). To meet this goal, the coding team approximated the percentage of intercoder agreement for the transcribed (first and second) interviews overall. It should be noted that the transcribed interviews were assessed using the Microsoft application, SharePoint. This application platform provided information-sharing and collaboration capabilities for the coding team.

Each coder's initially assigned codes (line-by-line) were compared for similarities and differences. Most were nouns used as labels describing the basic topic of a sentence or passage of qualitative data. Taken together, the open codes provided an inventory of topics for indexing and categorizing which was helpful in this case study that contained a variety of artifacts and documents. Collectively, there were roughly 263 first cycle codes or open codes assigned to the data collected. Second cycle coding provided a "way of grouping those [first cycle] summaries into a smaller number of *categories*, *themes*, or *concept*s" (Miles and Huberman, 2020, p. 79).

Axial Coding. Phase two involved the second semi-structured interviews with faculty participants. The second interviews probed faculty participants perceptions of design-based instructional practice. After the second interviews, a second coding cycle was conducted. In this coding cycle, codes from the initial coding cycle, as well as, any additional codes from second interviews were organized into groups of codes with similar properties. Again, second coders' assigned codes (line-by-line) were compared for similarities and differences. The codes developed by the coding team were then synthesized into categories that centralized around several core or axes of data findings. After being organized into categories, pattern codes were assigned. The pattern codes were explanatory codes that provided the bigger picture and a much more meaningful analysis of the study's overall findings. There were three pattern codes that resulted: course design, design process, and course management.

Additionally, document content analyses were used to produce another independent source of data for the study. The faculty participants' course documents, such as, syllabi, slides, and handouts, were collected and analyzed using a summative document content analysis method. And finally, triangulation of these multiple types of data collected, first and second interview data and document content analyses, was conducted. The triangulation method was incorporated to improve the trustworthiness of data findings and to aid the process of conceptualizing themes providing answers to research questions.

Researcher Positionality. My relationship with the research environment as an insider increases the richness and realism of content, connections, and contextual findings. My domain knowledge aligns with design thinking's theoretical attributes, the practitioner's experiences, and instruction of project-oriented courses. I spent the first 20 years of my professional career in Silicon Valley high tech as an electrical engineering in product research, design, and development. In these experiences I engineered many hands-on, ill-defined, authentic problem solutions focused on real world needs, products, and services. The engineering design methods employed a process and practice commonly referred to as “thinking-out-of-the-box,” tinkering, or “imaginative thinking.” My experiences were in social settings commissioned to create and innovate project-oriented designs and to focus on accomplishing “something collectively which could not be accomplished separately” (“The HP Way”, 2020). My engineering design process experiences are characterized in many slogans of prior decades, such as: “Invent, “Imaginative Thinking,” and Make it Matter” (Hewlett-Packard slogans), “Think” (IBM slogan), and “Think Different” (Apple Computer Inc, slogan, 1997 to 2002).

Subsequent to my engineering career, I became an educator and administrator at two local independent middle/high schools in the San Francisco Bay Area for 15 years. I incorporated the engineering design process learned and experienced with the popular slogans of the era. My strategies and beliefs emphasized project-oriented research and development, constructive thinking, and ill-defined problem solving. This background was applied in the courses that I taught: mathematics, engineering, project-oriented clubs, maker spaces, wide range of curricula (design and non-design cultures), and STEM programs with emphasis on girls. In these teaching and learning environments, I immersed students and faculty in hands-on design challenges and activities to engage in thinking and iteration of new ideas and fun projects. I also exchanged classroom visits with the Stanford d.school and pioneered a 12,000 square foot engineering design facility for middle/high school students.

Challenges articulating what design thinking instructional practice is and how to provide meaningful professional development and pedagogical examples animate the purpose for this descriptive study. Using a reflexive researcher approach, I am making a concerted effort "to tell it as it is" from the faculty participants' perspectives, instructional practices, and reflections. I acknowledge the possibility that my reflexive approach can threaten the validity of findings and have therefore bracket this experience at the onset of the study. The reflexive researcher approach can also add credibility and validity to the research – an important factor in the inductive process of qualitative research. There are advantages for findings that are (a) co-constituted with the faculty participants, (b) share connections to the world of the faculty participants producing theoretical understanding and sensitivity, and (c) leverage insider experience to reflect an ability to "construct meaning that would not be apparent to an outside" (Jootun et al., 2009, p. 45).

Throughout the data collection and analysis process I kept memos of my thoughts about participant comments and research process developments. I used these memos to reflect on my own assumptions and biases and how the research experiences were shaped by my background and experiences. Again, the intentionality was to build on my background and experiences shared with faculty participants. And through this process of building on my domain knowledge, the advantage was the ability to add credibility and validity to the research.

Trustworthiness. The researcher lens or viewpoint contributed to the study's trustworthiness. According to Creswell and Miller (2000), this viewpoint leaves it up to the researcher to determine how much time will be spent in the research environment to establish good themes for the topic and to make sense of the findings (p. 125). The rigor of this lens was described by “triangulation of data collection strategies … to tell the story” (Speziale et al., 2011, p. 208).

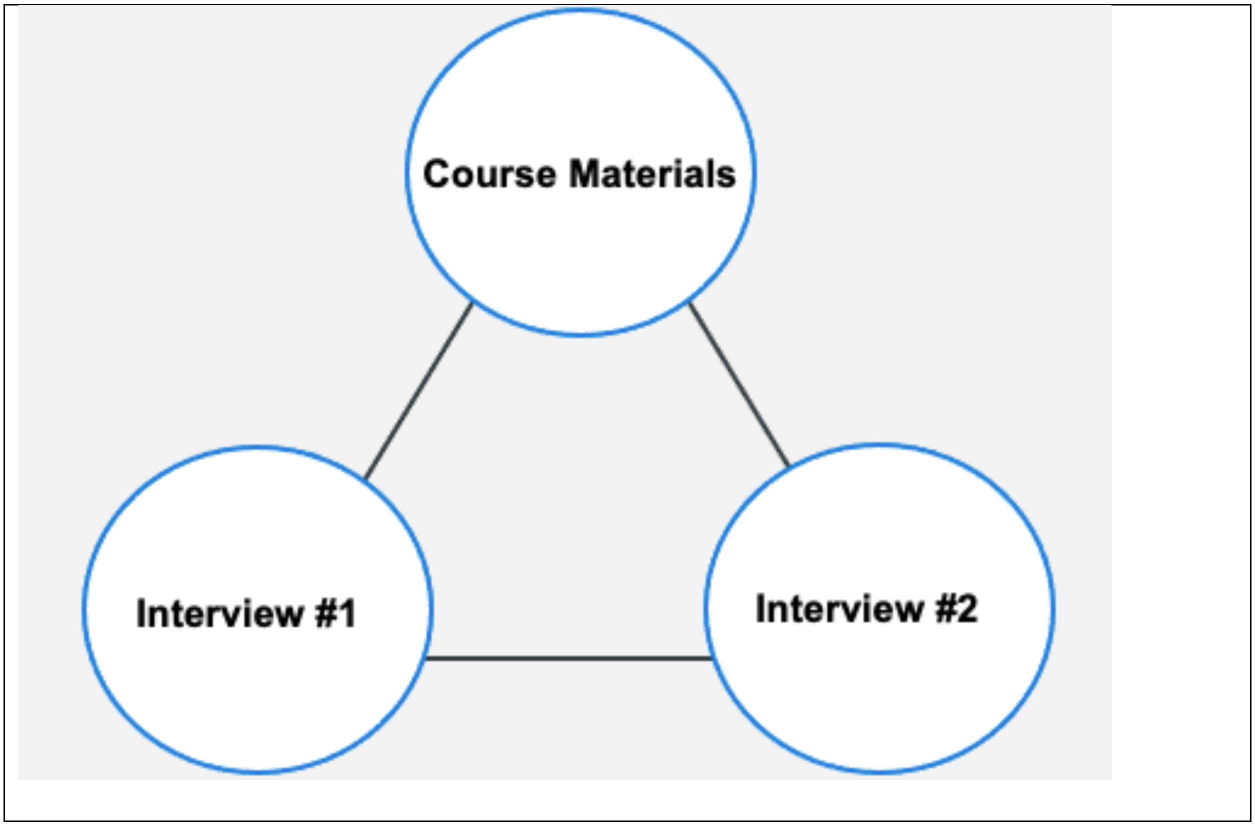
The researcher is trained and has worked as a design-oriented professional and educator. She identifies with the faculty participants’ experiences as an insider. This identity is both an advantage and threat to trustworthiness. From the onset of the study faculty participants were informed about my background, the study, and that their anonymity was guaranteed. The actual names and courses of faculty participants are not revealed in recorded and transcribed interviews. Pseudonyms were used to report the study’s findings. The participants were informed that I would be using bracketing to separate my experiences from theirs.

Regarding the researcher’s lens viewpoint of establishing trustworthiness; I acknowledge the impact of possible biases from my background and experiences. Because of my background, credibility advantages and judgement threats can potentially influence data collection and analysis as a reflexive researcher. My intent is to identify and separate personal views and biases from the study’s data collection and analysis. Thus, bracketing my background and experiences that align with the faculty participants’ experiences creates an open and honest narrative.

Bracketing is a perceptive process on the part of a reflexive researcher of putting aside personal background and experiences in order to not make judgements about what will be observed or exchanged in interviews. Bracketing is a better position in researcher reflexivity to approach findings honestly and openly (Jootun et al., 2009; Speziale et al., 2011). Further, “the view adopted by many qualitative researchers is that there are many socially negotiated meaning… multiple interpretations of the same reality” (Jootun et al., 2009, p. 45). When given multiple interpretations or views of the same reality it is possible to strengthen the case to be made for subjectivity. Rather than excluding the reflexive researcher, there is a good case for providing reflexivity because this viewpoint “adds rigour to the process” (p. 450).

Creswell (2009) recommends for the research proposal “one or more strategies available to check the accuracy of the findings … as well as convince readers of that accuracy” (p. 191). For this reason, the researcher chose triangulation and member checking. “Triangulation is a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study” (Creswell & Miller, 2000, p. 126). Triangulating different data sources - course documents and materials and two semi-structured interviews (pre- and post-classroom observation) - will be used to build a “coherent justification for themes” (Creswell, 2009, p. 191). After triangulation, member checking was used to determine the accuracy of transcribed interviews. Convergence among the multiple sources of information is important when providing an accurate description of the two faculty participants’ perspectives, instructional practices, and reflections. And finally, member checking was used to add rigor to the study’s trustworthiness when reviewing the researcher’s findings, themes, and rich, thick description (p. 191; see Figure 7).

Figure 7. Data Analysis – Triangulation
(Banks-Hunt, J., 2020)


Course Materials
Interview #1
Interview #2

Findings

The findings of this research study involving a small purposive sample of participants teaching senior engineering design-based capstone courses are detailed in the following section. The faculty participants described not only the overall structure of their design-based course, course-based activities, and course management, but also why the content and context of open-ended, real-world problems were chosen for the course design. The analysis of collected data included faculty background information, document analysis, themes and related evidence, and perceptions of design thinking preparation and instructional practice.

Research Questions and Themes. The overriding research question guiding this study is: What can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity? This overarching question was divided into two research questions for this case study:

RQ1. How are faculty participants' perceptions of developing and implementing design-based courses informing "designerly" ways of instructional practice?

RQ2: How do faculty perceive that their instructional practices engage students in design thinking activities?

After examining the findings from the case study, two main themes emerged to answer the research questions, each with its own sub-themes:

Theme 1: "The nature of design is different than traditional textbook learning."

- Sub-theme 1: "We don't use a textbook."
- Sub-theme 2: "Always look for novel ideas or creative solutions" for problems with no right answers.
- Sub-theme 3: "Focus on a lot of team building" and a diverse team is critical.

Theme 2: Connecting students' learning engagement to tangible experiences and processes of design-based instructional practice for realistic exposure to real-world problems.

- Sub-theme 1: Course design for realistic exposure to real jobs.
- Sub-theme 2: Design process is not a cookbook, but rather, hands-on experiential learning in design-based courses.
- Sub-theme 3: Design process for hands-on, experiential learning in iterations.
- Sub-theme 4: Course management tools useful for a variety of different purposes also enable team-based artifact making for design solutions.

Research Question 1. How are faculty participants' perceptions of developing and implementing design-based courses informing "designerly" ways of instructional practice? The first semi-structured interview was an initial information gathering conversation with Virginia and Elliott. The data collected provided an understanding of faculty participants' perceptions about the structure of their design-based courses to engage students in a "designerly way of thinking and communicating that is both different from scientific and scholarly ways of thinking" (Archer, 1979, p. 17). When problems are open-ended and do not have prescribed textbook solutions, a designerly way of thinking is useful in addressing these real-world, open-ended problems, some that result from every day experiences and others that are innovative advances. The open-ended, real-world problems typically do not enable the problem solver to arrive at a means of meeting viable solution requirements "simply by transforming, reducing, optimizing or superimposing the given information alone" (p. 17). They do, however, rely on creativity and thinking-outside-the-box to design and make artifacts that satisfy desired needs. The data collected and the emergent themes provide evidence to understand the faculty participants' designerly ways of instructional practice to engage students in problem-solving activities useful for designing and making product/project artifacts for real-world, open-ended problems.

The first semi-structured interview collected data to explain the faculty participant's perceptions of preparation for teaching a design-based capstone course, which is specifically tied to Research Question 1 (RQ1). The data were focused on how the faculty participants came to teach a design-based course and the overall design of the course. The respondents discussed course content and the essential components of their course design. RQ1 probed a number of course design topics: course goals and objectives; students' resources, skills, learning outcomes, and takeaways; challenges and successes; and instructional assistance (Graduate Teaching Assistants, departmental, and industry partners).

<u>Theme 1.</u> ***"The nature of design is different than traditional textbook learning."*** The first theme of the study summarizes Virginia's and Elliott's perceptions of developing and implementing design-based courses as the overall finding of RQ1. Theme 1 establishes a key difference between *design-based courses* and courses that are based on *rote learning.* Some educational psychologists describe this difference between learning with understanding and rote learning in terms of the amount of long-term memory storage required. "Learning with understanding requires large amounts of linked information to be stored in long-term memory" (Sweller, 2008, p. 216). Other researchers, such as Simon (1996), describe the difference between rote learning and learning with understanding in terms of reiteration of known answers optionally using different parameters. "When something has been learned by rote, it can be regurgitated more or less literally… Partly it is a matter of redundancy: meaningful material is stored redundantly, so that if any fraction of it is forgotten, it can be reconstructed from the remainder" (p. 101). Applying this background, learning with understanding in design-based courses suggests larger amounts of long-term memory storage, as well as, eliminating restatements of content or known answers more or less literally.

Theme 1 is supported by three sub-themes: (a) "We don't use a textbook," (b) "Always look for novel ideas or creative solutions" for problems that are open-ended and do not have right answers, and (c) "Focus on a lot of team building" and a diverse team is critical. Theme 1 and the three sub-themes communicate perceptions of design-based courses that are different from textbook, rote learning courses that, as a standard, do not implement learning from open-ended, real-world problems and the use of "designerly" ways of developing problem-solution artifacts.

Sub-theme 1: "We don't use a textbook." Virginia's and Elliott's responses to questions in the first interview focused on their perceptions of preparation for teaching a design-based course. Their preparation for engineering design-based courses suggested differences from courses that are textbook-based, rote learning, and prescribe single right answers. The pedagogy of design-based courses is not textbook-based because the course content is open-ended, real-world problems and requires student learning outcomes and attitudes toward thinking-out-of-the-box to design solutions.

Virginia and Elliott exposed students to problems that provided opportunities to make pedagogical decisions that met external standards of accreditation authored by The Accreditation Board for Engineering and Technology (ABET, 2020-2021). Virginia's course outcomes and pedagogy met the general criteria of ABET Criterion 3, Student Outcomes:

> The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. (ABET, 2020)

Criterion 3 has seven outcomes focused on the practice of engineering, such as, "an ability to apply engineering design to produce solutions that meet specified needs." Virginia's pedagogy prepared students to achieve these types of course learning outcomes. She stated, “I can say we don’t use a textbook” and the student learning outcomes for her course were “largely copied from ABET criteria,” for example, "identify, formulate, and solve engineering problems" (Course Outcome #2) and “design a product or process to meet desired needs" (Course Outcome #5). In addition, Virginia included a specific section in her syllabus titled, "Relationship to Student Outcomes: This course contributes to the fulfillment of the following ABET Criterion 3 outcomes," that lists the six ABET student outcomes that the course fulfills (i.e., outcomes 2-7).

On the other hand, Elliott’s course outcomes and pedagogy met the general criteria of ABET Criterion 5, Curriculum:

> The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The program curriculum must provide adequate content for each area, consistent with the student outcomes and program educational objectives, to ensure that students are prepared to enter the practice of engineering. (ABET, 2020)

Criterion 5 has four parts focused on the nature of the curriculum. In Elliot's syllabus, he specifically states, "this course is designed to meet ABET Criterion 5", and lists the fourth part of Criterion 5: "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" (ABET, 2020). Ultimately, Elliott’s course objectives were to prepare students for engineering real-world practice through a curriculum design that required a major design experience. The major design experience ensured that students, not choosing academic study continuation after graduation, were prepared to enter the real-world of engineering. In addition, Elliott's pedagogy was built on students' prerequisite preparation in traditional, standard, non-design courses. The pedagogy expanded upon students' textbook knowledge to develop skills and knowledge useful for solving open-ended, real-world problems. He stated, "now you have to take knowledge and start to assemble it into a product that basically will solve the initial [real-world] problem."

Both Virginia's and Elliott's responses confirmed a pedagogical shift from traditional textbook-based rote learning to student outcomes and curricula that prepared students for real-world problems. Virginia's pedagogical decisions were influenced by ABET Criteria 3. Her students engaged in open-ended, real-world problems that did not have known right answers. Students relied on thinking-out-of-the-box to expand upon problem-solving skills gained in courses that preceded the engineering senior design capstone courses being taught. Elliott's pedagogical decisions were influenced by ABET Criteria 5. His students engaged in creative thinking to generate design ideas that potentially resulted in cutting edge design solutions. Both pedagogical decisions contributed to the development of design-based courses to inform designerly ways of instructional practice. These practices, although different from scientific and scholarly ways of instructional practice, are as effective in open-ended, real world problems.

Sub-theme 2: "Always look for novel ideas or creative solutions" for problems with no right answers. Virginia also communicated differences between design-based courses and textbook, rote learning courses. One essential difference is design-based courses are useful for generating novel ideas or creative problem-solving. Virginia stated, "the nature of design is different than traditional textbook learning…because there is no right answer, I think, design courses are inherently different than standard classes." The homework she assigned in her design-based course engaged students in learning outcomes that promoted designing and making artifacts or creative solutions and were different from standard textbook homework assignments. She indicated that "If you're used to understanding a particular topic and then regurgitating those problems with different parameters and that's how you learn, you might not be set up to learn as well in a design-based class because there is no right answer and you have to think outside of the box and be a little bit more creative." She added:

> What's core to the class, I think, is working in a team and …the hands-on part…design work doesn't have to involve novel solutions…you could be a designer reducing the cost of something…Teams try to think about potential solutions… to figure out which ideas could work and which couldn't and maybe evaluate which ones would work best.

The homework assignments in Virginia's syllabus required students to design and evaluate solutions to open-ended problems that met design specifications and possibly introduced novel ideas. She referenced a lesson plan that involved two problems. The first problem was a thermodynamics textbook problem where she was concerned about "teaching a thermodynamics problem and everybody does the problem the same way and everybody gets the right answer." She added limitations of solving only textbook problems was that "students have difficulty recognizing relevant concepts and principles, and putting them together in order to solve these problems."

Virginia also used a second problem that was an open-ended, real-world problem. The second problem involved a special purpose vehicle-hitching mechanism for transporting a grill to be used during football season tailgating events. The grill transportation problem was not found in a traditional textbook and did not have a right answer or prescribed known solution. In the grill transportation problem, (a) students defined the problem, (b) selected design alternatives, (c) used design, analysis, and experiential learning to test the selected design alternative, and (d) created a final project proposal/presentation based on designerly ways of creating product-solution artifacts.

Elliott's responses also included references to the importance of "being able to think outside the box and maybe come up with something that's very creative." Because the questions and problem assignments in his course were open-ended and without known right answers, unlike problems in textbooks, it was his aspiration for students to push themselves to design unique ideas and solutions. Elliott stated that final design results demonstrated great skills that students applied to homework assignments, "but they're not pushing themselves to look at some real edge burners." He wanted students to think deeply about design ideas "and maybe come up with something that's creative that propels them into the next level." He aspired for students to experience the creativity needed to raise the level of ideas to design novel ideas or cutting-edge design results. He set the bar high for students when suggesting the "real edge burners" of novel ideas. It was his perception that novel ideas propel design results to the next level or "the innovative side, which is more like Tesla." He identified with creative thinking that resulted in "a lot of the thoughts that [Thomas] Edison would have where he says, 'Hey always look for novel ideas.'"

The context of Virginia's and Elliott's references to open-ended, real-world problem requires thinking-outside-the-box and the experiences of designing and making problem solutions when there are no textbook right answers.

Sub-theme 3: "Focus on a lot of team building" and a diverse team is critical. According to Virginia and Elliott, teamwork was a key component of course learning outcomes. Teamwork provided students opportunities to collaborate, design, and make solutions for a problem of their choice selected from a collection of real-world problems offered in the design-based course. Their students were expected to work with a team of peers to tackle real-world problem assignments. Project teams in both Virginia's and Elliott's design-based courses had a faculty advisor and a detailed syllabus to guide students through a curriculum focused on open-ended, real-world problems. Teamwork also involved mentorship, and for this reason teams involved industry partners and departmental research faculty.

Virginia organized groups of 9 or 10 students per team. Because she taught a large class of over 400 students, roughly a third of the projects came from faculty ideas and the remaining projects were sponsored by industry partners. She believed a design-based course was different from other classes. She stated design-based courses required, "working in a team and physically building something." And because the design-based course was team-based, "students can't just do their homework in a vacuum by themselves." She acknowledged that most of her students did not have prior exposure to teamwork-building "and they might be working on a team for the first time." For these reasons, she walked students through the syllabus at the beginning of the course to emphasize teamwork objectives and the importance of meeting "at least one hour per week with all of the students on the team and their faculty advisor."

Virginia's syllabus described a number of course objectives regarding what project teams would be doing. One of the project team course objectives included team-based homework assignments. Another team-based course objective, the critical design review (CDR), was a key presentation assigned at strategic points in the two-semester design process. The CDR presentation summarized various design-based team activities and whether or not the team's product design was meeting target specifications. "It is expected that all design teams (with a few rare exceptions) will deliver a physical product that is demonstrated to meet the established design requirements." And lastly, team-based course objectives required individual team members to maintain an engineering notebook about the product/project development process. The engineering notebook was evaluated in peer reviews by the team and by graduate teaching assistants (GTAs). Peer review team assignments were conducted "regularly so students can evaluate their team members on key team work characteristics."

In brief, Virginia's teamwork learning objectives included the ability to (a) "recognize and define problems," (b) design and conduct experiments as well as analyze and interpret data," and (c) "generate multiple design concepts and down select to a feasible set based on objective criteria." While these objectives may sound individualized, they were implemented through team-based projects. For example, graded design team deliverables/homework assignments included "an engineering notebook that maintained detailed notes about the project and work hours." Gantt charts maintained the project schedule, and oral and written presentations communicated various stages of the product development and final project.

Finally, Virginia wanted students to take away teamwork skills from the course. "Students have to practice actively being on a team and there's a lot that can be unpacked there in terms of interpersonal skills, communication skills, conflict resolution, personality differences." Students needed to demonstrate the ability "to function effectively as a member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment."

Elliott described how he put together teams. The team experience was a skill that his students were working on in the class. He stated, "the ideal team size and most people's opinion is four [students]." It was his philosophy that "when you get over four, it makes it very hard to be able to know if somebody is really contributing significantly to it [the project] and gaining the experience that we want them to have." For this reason, he solicited projects from a variety of different sources including industrial, governmental, and the department's research faculty to have enough projects for organizing students into teams of four. Some years, Elliott had enough projects to have the desired small teams of four students, and in other years, this was not the case. Although teams were made of students from one discipline, Elliott looked forward to making these teams "truly interdisciplinary…we've got to get into a situation that we're having multiple larger teams working on larger projects in a multidisciplinary area…but we're still too siloed."

Elliot's syllabus was linked to another course document entitled, "Fall 2019 Schedule," which provided a detailed list of individual and team-based assignments. He stated teamwork goals required students to "learn about themselves and about others and about how to come up with solutions within the team." Teamwork defined how students were to work together to "share the workload, learn from one another, and assist one another in the design process of developing prototypes and products of collaborative ideas." According to Elliott, "we focus a lot on team-building…it looks like team-building is something that has to be a part of the design process … and that they're helping each other along the way."

Additionally, Elliot's syllabus described a number of teamwork-based course objectives that provided "the opportunity to solve real-world problems…almost all of the work done in the course sequence will be teamwork and you will have the opportunity to develop team leadership and/or team membership skills." Student teamwork learning objectives included the ability to (a) "develop effective team approaches for [real-world] engineering solutions", (b) "apply appropriate and accepted planning strategies to open-ended design projects and maintain accurate project records and project schedule", and (c) "build/test models or prototypes and refine the most feasible design." Typically, graded homework assignments were also team-based. Team-based homework assignments included project notebooks for recording team-based design ideas for building/testing/refining prototypes, Gantt charts for maintaining accurate project schedules, and presentations on various stages of the major design experience.

Elliott allowed time at the end of every class session for teamwork meetings/information exchange. It was during in-class team meetings that he observed teams come together. He described these observations as the time spent together and spending "a little bit more time discussing through why they selected the things they did." Teams figured out how to divide the assignment among themselves. Elliott shared:

> Quite honestly, I've never observed them in their own team meetings except when I watch them in laboratories…I'm sure what happened is that basically they talked as a team, they divided it out where different areas they would like to pursue, they'd go off and do that independently and then they'd come back and start discussing it…they will say, 'We've got this task.' They'll have somebody assigned to start doing some thinking about that particular assignment…they will start brainstorming together on that particular task… to share the workload.

In summary, Elliott's and Virginia's syllabi consolidated design-based course information into a textbook-like document. Their syllabi encompassed teamwork expectations, problem-solving skills development, and homework focused on defining a real-world problem solution for the major design project. Both Virginia and Elliott's course goals and objectives concluded with a final team-based product presentation and written report at the end of the course. According to Elliott, "teams have to help each other overcome the obstacles of collaboration …and the other attitude is that when working in a team, a diverse team is critical."

Theories of design and design thinking, in particular Simon's (1996) persuasive argument on learning-by-doing acknowledges meaningful understanding, constitutes new knowledge and problem-solving in the domain of open-ended, real-world problems. The argument acknowledges that "every teacher knows that there is a profound difference between a student learning a lesson by rote and learning it with understanding, or meaningfully" (p. 101). Research Question 1 explored faculty perceptions of developing and implementing design-based courses to inform "designerly" ways of instructional practice.

Regarding the development and implementation of design-based courses, the context of their courses was very similar. The context of Virginia's course was open-ended, real-world problems. The context of Elliott's course was what he called, "good problems." In both cases, the context was real-world problems that were open-ended and did not have right answers. With that foundational piece established, Virginia and Elliott built design-based courses that did not use textbooks and provided detailed course syllabi. The course syllabi were repositories for the important course information, such as goals, objectives, topics, assignments, a range of deliverables, and summary of student learning outcomes. Virginia's syllabus was influenced by ABET Criteria 3 and was focused on student outcomes. The syllabus covered topics structuring student learning to prepare them to enter the professional practice of engineering. Elliott's syllabus was influenced by ABET Criteria 5 and was focused on curriculum requirements. The syllabus documented the curriculum of the design project and the steps in the engineering design process, and in a separate document, he provided the actual weekly schedule of reading assignments and homework deliverable.

In terms of how the design-based courses were implemented, Virginia and Elliott suggested a pedagogical shift from the rote learning practices of traditional textbook-based methods to methods that engage students in homework assignments and projects that step them through the intellectual activities of designing and making (construction) knowledge artifacts to address problems that do not have known solutions. When problems have known solutions, “It seems clear that repetition plays another role in rote learning; namely, that of strengthening or reinforcing associations once they are formed” (Rock, 1957, p.193). To accomplish these intellectual activities involving open-ended, real-world problems, both Virginia and Elliott spoke about students thinking-outside-the-box to define the problem(s) and generate ideas. The overall structure for the courses involved students working teams and not in a vacuum of isolation. Team-building assignments, therefore, were key to implementing student learning outcomes of design-based courses and provided students opportunities to collaborate with peers when tackling problems in the course. Teams practiced defining problems, generating concepts, using productivity tools for project management, and preparing presentations and project reports as midterm assessments; specifically, approaches involved preparing product design specifications, Gantt charts, Excel spread sheets, engineering notebook entries, and effective communication to audiences via oral and written presentations. Teams practiced determining which ideas could actually work and which ones would likely work best. These assignments stressed the importance of challenging students to think deeply and to come up with creative and novel ideas.

All of the project teams in the design-based courses included a faculty advisor and some of the teams included both a faculty advisor and industry professionals.

Regarding the implementation of design-based courses, introducing the design process and hands-on experiential learning are the key components. In the implementation, all project teams engaged students in the actual practice of dessigning and making artifacts of knowledge and were encouraged to take risks in the design process in order to come up with novel ideas and creative solutions.

Research Question 2: How do faculty perceive that their instructional practices engage students in design thinking activities? The second research question (RQ2) was answered primarily through an analysis of the second semi-structured interviews. In particular, the interview data provided information on how Virginia and Elliott perceived that their instructional practices engaged students in design-based course activities. According to Virginia, the design-based activities or course “assignments are the same for every team even though the projects for every team are vastly different.” She used the course assignments and course deliverables to step students through what takes place while the design process is going on. According to Elliot, design-based activities comprise what he calls “a comprehensive process for looking at how to manage a design process as far as looking at the time requirements, the economics, and then [product] development.” His syllabus, a different source of data, also referenced the comprehensive design process to provide a picture of what takes place while real-world problem solving is going on. Thus, they believe that course assignments, course deliverables, and the comprehensive design process, are useful for engaging students in what is involved in design-based instructional practice to engage students in design-based thinking activity.

***<u>Theme 2</u>*: Connecting students' learning engagement in learning to tangible experiences and processes of design-based instructional practice for realistic exposure to real-world problems.** The second theme of the study concerns Virginia and Elliott's perceptions of design-based instructional practice and summarizes the study's findings for RQ2. Theme 2 establishes the design process or product development process for solving open-ended, real-world problems. Theme 2 is supported by four sub-themes: (a) course design for realistic exposure to real jobs; (b) design process is not a cookbook, but rather, hands-on experiential learning in design-based courses; (c) design process for hands-on, experiential learning in iterations; and (d) course management tools, useful for a variety of different design project purposes and team-based artifact making for designing and making solutions. Theme 2 and the four sub-themes communicate perceptions of design-based instructional practice to engage students in design-based activity. Virginia and Elliott responded to this research question by giving their perceptions of what is involved in the course-based activities to create an open-ended, real-world product design solution.

Sub-theme 1: Course design for realistic exposure to real jobs. Virginia's and Elliott's interview responses focused on course goals and objectives that provided a more realistic exposure to real jobs through a design-based instructional practice. Their syllabi contained a number of similarities and differences. Both of them provided individual and team-based assignments. Students' completion of course assignments were evaluated on assessments, such as their ability to follow a design process, prepare a project proposal, design and iterate on the proposed product/project specifications, construct desired design results, and communicate design results effectively in oral and written design reviews. Solving open-ended, real-world problems fostered students' thinking-out-of-the-box in preparation for real jobs. Students engaged in hands-on, experiential design-based activities to complete individual and team-based homework assignments and projects. However, Virginia and Elliott had differing opinions of engaging industry partners and controlling the size of design teams.

Virginia and Elliott engaged industry partners in their design-based courses, but not to the same degree of involvement. Virginia involved industry partners as project sponsors, mentors, guest lecturers, and final presentation judges. She “added aspects to the class to bring in a more industry-centered perspective and less academic-centered perspective.” Virginia developed “relationships with the companies that [I've] worked with over the last five years and I will reach out to them and say, ‘Would you like to do another project?’” Virginia believed that “students that are on the industry sponsored teams are getting a more realistic exposure to what their real jobs might be.” Virginia established the importance of industry partners when polling her students over the five years teaching design-based classes:

> Because if you look at the numbers, somewhere between 10 and 15% of our students go to graduate school. So, the other 85 to 90 are going to industry. So, if we're just teaching the students what career academics know, we're preparing 10 to 15% of them, but not the other 85 to 90%. So, I felt like they needed to hear more about what it's like in industry.

Virginia’s syllabus also focused on other ways to expose students to real-world problems, such as, “solving an open-ended problem that is unlike other problems you [students] have solved in most classes.” Overall, it was her course goals and objectives to engage students in “a more realistic exposure to what their real jobs might be.” She used professional language skills to “talk to them as if they are employees and maybe not students” as a way of making the course different from prerequisite courses. She stated, “but if I had to boil it down, I would say one, they'd [students] leave with an understanding of the product development process, and two, they would leave with a feeling like the class was a little bit like practice for their first job."

While Virginia proactively sought out industry partners for engagement in study projects, Elliott did not. Elliot viewed the engagement of industry partners as problematic. Elliott limited the involvement of industry partners to sponsorship of just a few projects: "A lot of times they'll say [industry partners], 'Well, if we were doing that problem, we would do X instead of this.' Well, that's not very useful …sometimes they were involved in presentation judging, et cetera, and that's the closest that I have on what I call industry feedback." Elliott established a limited role for industry partners based on several issues related to conflicts of interest and ownership of novel ideas and students' patents:

> And that's always a problem with industry is that the other thing they don't understand is that this is a student project, so therefore they own the patents on these things. And so, a lot of times they feel like, 'Well, I brought you the problem, I should get the solution as well.' But it doesn't really work like that in your own industry or in their own company. And so that's been one of my challenges.

Elliot specifically discussed the issue about patents with his students at the beginning of the course. It was his course management instructional practice to minimize inclusion of industry partners in students' design teams. Design team products that are eligible for the patent process can cause bad feelings among design teams, industry partners, and/or advisors. Industry partners will like to claim the patents as theirs. Elliot established clear understanding for his design-based course that limited the role of industry partners to final presentation judges only in order to diffuse any claims on ownership of solutions and patents: "but sometimes there's bad feelings amongst the group because they're not able to say, 'That's my patent and I'm a part of it.' And so that has to be some real clear understanding from the beginning about that."

In pursuit of realistic exposure to real jobs, while shunning industry partner involvement, Elliott instead focused on "good problems." That is, "we focus on the ABET [criteria] and that we try to emphasize that these are real world types of engineering problems." It takes time to think about real world problems that can be completed within the time constraints of two semesters. Elliott explained, "one of my first items is setting a good problem…and so I think the critical item is, really looking at the projects that students are working on and is it realistic that they can get it done in two semesters." On the issue of projects, another issue Elliott faced is the administration of students choosing their projects.

Elliott's strategy for controlling students' project selection and team size was to keep project teams to four students based on his philosophy and the experience and opinion of faculty in his department. His philosophy and experience suggested that "when you get over 4, it makes it very hard to be able to know if somebody is really contributing significantly to it [the project assignment] and gaining the experience that we want them to have." To facilitate this concern, Elliott sent the list of projects suggested for the coming fall semester to students eligible to take the course. He stated, "I started sending the projects that you [students] will be able to choose from. And my hope is they start looking at them…and they will start trying to form teams within themselves." The challenge is, however, that Elliott typically does not have enough projects to organize project teams with four students, and students in his course choose to be on project teams that are much larger. He stated,

> I didn't have the projects that I really needed and so we ended up with 10 projects amongst 51 students. I think I only have one team that has four and is the smallest

> team. And then I've got some that have 9 or so…almost all of my challenges are based on the project anyway you cut it.

Elliott assessed that his greatest challenges were not having enough projects to maintain project team sizes of four students and having difficult projects, especially for the bigger teams. Some years is was difficult for the department to define enough open-ended real-world problems to support smaller design teams and other years students did not sign up for some of the projects suggested by the department. He also assessed that the bigger teams completed the difficult project assignments by doing "a good job of dividing out and trying to conquer the problem."

Virginia's and Elliott's courses incorporated team-based assignments that culminated in a final, comprehensive, real-world engineering design project. The final products/projects were developed by design teams selected by the students, while the syllabus guided design teams through the problem-solving steps of the product design process over two semesters. Design teams were expected to "apply appropriate and accepted planning strategies to open-ended design projects and maintain accurate project records and project schedule." The open-ended design projects were sponsored by industry partners and departmental faculty to engage students in "the opportunity to solve a real-world problem using skills developed during the last 3-4 years as an [undergraduate] student."

Sub-theme 2: Design process is not a cookbook, but rather, hands-on, experiential learning in design-based courses. Elliott further explained that the real-world product development process involved "good problems [that] are not cookbook type items…if it was already solved, we wouldn't be talking about it." His use of the cookbook analogy clarified the meaning of good problems that were not activities arranged in well-known step-by-step processes. Experiential learning activities engaged students in challenges that required them to:

> Step away from it [the textbook] and to be able to put some engineering into the process of finding the solution(s) to real-world problems…as we implement this [solution] within a system…And just because you came up with a neat solution doesn't mean that it doesn't have side effects that may impact the system.

Elliott discussed the process of finding good problems for the course. "We go through it about this time every year… I start trying to solicit from a variety of different sources …industrial, a governmental standpoint, and from my research faculty." This problem-finding process was necessary for the pedagogy to shift to "really looking at the projects ….to give enough flexibility that we have unique problems that aren't the same every year and that are real world items."

Elliott also discussed the problem-solving approaches for tackling these problems that are "typically a very complex problem." He gave examples that the problem complexity "might be through technology, that might be through a process, or it could be a desire for an end product of some sort." He suggested that there were two types of design teams and used the contrast between the words, conservative and creative, to describe the differences in final design results or outcomes. Innovative teams "think outside the box and maybe come up with something that's very creative." Students that think "if they take a huge risk and it fails, and their grade is going to be reflected by it," are sometimes very conservative. And, because of these contrasting design team approaches, conservative and creative,

> You have to remember that the light bulb for a variety of the teams comes on at different times…We [innovators] could build something that's out of this world, but now we have to fit it into the world…a lot of things that I was trying to do even during class is doing coaching [design teams].

Thus, according to Elliott on the topic of novel ideas, many of the final design outcomes are often very conservative.

Virginia, on the other hand, suggested that design results are not just about the differences between conservative and creative design teams, but also about understanding what is learned from hands-on, experiential learning. Virginia explained that design teams can put parts of the product design together using computer aided design (CAD) modeling and "it all looks really straightforward when on the computer." But, when the parts arrive and the team is looking to fit them together perfectly "and they won't go because of friction," the team begins to understand the importance of engaging in the hands-on part. She further explained the scenario:

> You're looking at this part and you're looking at this other part that goes with it and you realize there's no way to connect them together, CAD doesn't tell you [about friction]. But when they actually get their hands dirty doing it, they have these light bulb moments where they're realizing how much more important it is to have the hands-on experience than just the CAD experience, and I think they learn from that.

The design results of open-ended, real-world problems engaged design teams in problem-solving problems that are not in the textbook and have no right answers. Furthermore, the design process engaged conservative and creative design teams in the importance of hands-on experiential learning.

In summary, Virginia and Elliott incorporated good problems that were open-ended, real-world problems that did not have right answers and were not textbook or "cookbook" learning examples. Their students were solving problems from a collection of projects suggested by industry partners and/or department faculty. Problem-solving required these light bulb moments when teams are taking risks and understanding the importance of creativity (thinking-outside-the-box) and hands-on experiential learning.

Sub-theme 3: Design process for hands-on, experiential learning in iterations. The instantiation of the design process of hands-on, experiential learning was key to design-based course activities. According to Virginia, “a design course can be a lot of different things.” In Elliott’s case, the design-base course identified the steps of hands-on, experiential learning activities to select and solve one of the real-world problems in the list of projects offered in the course. The hands-on, experiential learning activities that he referenced emphasized “a repetitive or circular type process where you’re always coming back around and looking at your potential solutions.” Elliott’s syllabus summarized the overall design process steps:

> 1) identify the problem, 2) identify criteria and constraints, 3) brainstorm possible solutions, 4) explore most feasible solutions, 5) select one or more feasible solutions for more in-depth design, 6) build/test models or prototypes, and 7) refine the most feasible design.

Elliott suggested that although the design process was outlined in steps, the process was conducted as an iteration of steps. Elliott’s design process was organized with enough flexibility for students to iterate on any of the steps. Each iteration involved “thinking-outside-the-box of how to present that process in a way that might be a little bit unique.”

Elliott addressed students’ perceptions that design process failures might have a negative impact on their final grade in the course. “I keep emphasizing with the students that failure is not something that you should look at as the stopping point. It’s usually a beginning point that you proceed ahead with.” He was determined to convince students that “the attitude that [he] would like for them to take is one that has more risk-taking in the design process to overcome design challenges and obstacles." He was committed to raising the level of students' willingness to take risks and to involve their thinking and creativity in teamwork for "helping each other along the way." Elliott wanted his students to push themselves, especially when facing failure, to engage in new starting points, and "to look at some real edge burners that may push us into a whole new different direction." He wanted students to understand the value of iteration on refinement of ideas and solutions over their emphasis on just the final grade.

Virginia also emphasized the value of iterating in hands-on, experiential learning when stating, "we don't end at doing the analysis part." We make students actually build and test whatever the product is…and scaffolding not only across the whole fall semester but with each lecture and related assignment really helps them." The teams were able to utilize the support of scaffolding in the hands-on, activity to build and test project assignments and repeat attempts (iteration on ideas) to refine design results:

> There's no amount of classroom learning that can replace this hands-on activity of attempt, fail, repeat, attempt, fail, attempt, succeed. It's a really, really exciting time for the students and most of them tend to enjoy it, even though they find it to be hectic and exacerbating sometimes….We feel it's really, really important to teach them and for them to be able to transfer knowledge….We teach them the specific strategies and then they go apply them to their own project.

Virginia unpacked the product development process in the syllabus to outline what the design teams would be doing during various iterations of the hands-on, experiential learning experience.

> The first one is to recognize and define problems…formulate and solve whatever those problems are. In order to do that, they [students] need to be able to generate

> multiple design concepts …to make those decision based on objective criteria… to design and conduct experiments, and analyze and interpret data. And then from the softer skill side, we feel it's really, really, important to teach them and for them to be able to transfer knowledge on functioning on a multidisciplinary team. Communicating effectively, which is oral and written.

In summary, Virginia's and Elliott's described and enacted iterations of the design process for designing and making artifacts of problem solutions. Students were given guidance and support to complete these design processes that required thinking-outside-the-box when solving real-world problems in a hands-on, experiential learning context.

*Sub-theme 4: Course management tools enable design-based solutions***.** Virginia and Elliott discussed a number of course management strategies for guiding students to expected learning outcomes of the design process. The design process involved a number of hands-on, design-based activities. These activities engaged students in thinking about ideas, converging on the best ones, designing, and making prototypes of solving real-world problem. These prototypes were the artifacts or deliverables of the design process and the student learning outcomes of the design-based course.

Virginia's course management strategies were adaptations of product management experience and years spent judging senior design capstone projects as an industry partner. Her 20-year professional career in industry involved project management responsibilities in manufacturing companies. Virginia applied these product and manufacturing process management skills to design-based course management: "I brought a couple of new lectures in because I thought this is what the students were missing because I had industry experience and most of the previous instructors had not." As a professor of practice, she organized students' design team meetings, team-based homework, interaction skills among team members, effective communication (written and orally), and preliminary design reviews as the sole faculty member of the department's senior design capstone course. Virginia's course management skills were leveraged from professional career experiences spent (a) in industry as a product manager, and (b) in academia using an electronic classroom website. The experience as a project manager really prepared Virginia "for the organization required for this [design-based] class. Because I can be very organized, and I know what I need to do by what date because I write it all out and I keep my notes year to year." She organized her project management experience into student learning outcomes involving "schedules and check sheets, and certain notebook skills." And by learning course development tools in the academic environment, such as the use of an electronic website, provided the skills needed to "lay everything out…as an organizational tool. I'm not sure everybody [faculty] uses it that way, but I think it's great." These specific skills were used to teach design teams "concept generation and then they go apply them to their own projects. Virginia was teaching design teams product management skills.

> They're just not necessarily math and science-based plug and chug skills that they're more used to…they [students] might not be setup to learn as well in a design-based class because there is no right answer and you have to think outside of the box and be a little bit more creative.

Virginia's course management strategies taught design teams structured ways of knowing the design process. Students had to meet with their design teams and faculty advisor (a) "at least one hour a week," (b) "all teams have supplemental times during the week when they meet as just students without a faculty member to get homework done," (c) "every student is required to keep an engineering notebook," and (d) "finally, the team has to upload a homework assignment to the course website to be graded." This structure was important to keep homework assignments and deliverables on track.

Virginia also suggested a number of design process productivity tools to assist with keeping things on track. The productivity tools included Gantt charts, daily log books, engineering notebooks, and homework assignments. Virginia gave her students easy access to course materials: power point lecture notes and selected readings, the course website, recorded lectures, and the instructor's daily/weekly progress reports. Students attended two types of group meetings - a critical design review meeting held in the second semester and two scheduled group meetings every week.

Based on his experiences and background, Elliott's applied course management strategies were adaptations of several existing department goals along with other teaching experiences and interests in design. He has a Ph.D. degree and principal engineer's certificate (PE). When hired into the department, where he has been teaching the capstone course for roughly 20 years, he was one of only a few researchers with a PE certificate. The PE certificate was a credential preferred by the Accreditation Board for Engineering and Technology (ABET) for teaching hands-on, experiential learning courses. In addition, Elliott previously developed and taught an Applied Creativity course for technology degree students, engineering students, and agriculture students.

The course management strategies that Elliott incorporated and developed over the years in the engineering senior design capstone course involved setting students' expectations at the beginning of the course. He stated, "basically, I start off and within the syllabus we talk about the course description and some of the things that we have there." His strategy involved the use of productivity applications, project management tools, time management tools, "and other tools they need to understand and go out for continuous learning." The other project management tools included Excel spread sheets, collaborative writing, Gantt charts (to manage deadlines), LinkedIn courses, and project notebooks.

Elliott's course management strategies were a comprehensive process. "We're looking at how to manage a design process as far as looking at time requirements, the economics, and then four deliverables at the end of the spring semester." The comprehensive course management process guided students through the design process. "We go through several different times through the five steps of the design process…a lot of time in the fall semester talking about the problem statement." The syllabus consolidated important information about the design-based course in terms of types of problems, products to be designed, and the iterative design process taught in the course. The iterative design process was a way for students to refine design ideas and design results by circling or repeating any of the steps in the design process as needed to achieve desired outcomes.

In addition, Virginia's course management strategies included techniques for scaffolding students' engagement in the design process: "The assignments basically scaffold for the students how to get from knowing nothing about your project, to where they know exactly what their solution is going to be." Virginia provided support for roughly 40 design teams of approximately 10 students per team. Students also received support from teaching assistants (TA), industry partners sponsoring "approximately half of the projects," and department faculty who volunteered to be team advisors.

Virginia relied on other course management techniques to support students and design teams. Other techniques included lectures that break down the design process into topics as well as asynchronous meetings outside of class time with individual students and design teams, allowing them to discuss design process challenges and creative ideas for solving these challenges. She extended office hour appointments to her students, emailed, used discussion boards, provided weekly updates on the course website, and had an open-door, “walk-in” policy in the event that a scheduled meeting is during office hours. Further, design teams were required to attend weekly team meetings with either Virginia or a department faculty member. Other required meetings included Zoom meetings with industry partners and scheduled design team meetings with the graduate teaching assistants (GTAs). Teams also maintained engineering notebooks, Gantt charts, and other documentation, such as weekly progress reports and presentations summarizing design work-in-progress and outstanding issues related to making artifacts of the product development process.

These accounts provided by Virginia and Elliott informed what they were doing with course management strategies of instructional practices. They expressed the importance of hands-on, experiential learning in design-based courses. They also discussed course management strategies to guide and support students’ teamwork and course-based activities to design and make artifacts of real-world problem solutions. The strategies detailed in the interviews explained how students were given guidance and support to complete design processes that required thinking-outside-the-box and hands-on, experiential learning context. They also provided explicit information about supporting students when they are involved in the design process and what takes place while the design process is going on. Design teams relied on productivity applications to monitor, measure, and report product development progress (Gantt charts, Excel spread sheets, engineering notebooks, written and oral communication and presentations, preliminary design reviews (PDR), and critical or final design reviews (CDR).

In summary, Research Question 2 explored faculty participants' perceptions of how their instructional practices fostered design thinking activities. Designerly ways of knowing position "design as its own distinct 'things to know, ways of knowing them, and ways of finding out about them'" (Cross, 1982, p. 221). Noweski et al. (2012) proposed giving space to students to try out different methods, such as designing projects, that apply "abstract and general principles (instructions) in meaningful and responsible actions in life (construction)" (p. 78).

The faculty participants' design thinking activities provided students a realistic exposure to what their real jobs might be. This engagement was realized through teamwork, design projects, and a variety of design-based deliverables to inform student learning outcomes. The faculty participants assembled a variety of real-world projects for design teams from a variety of different real-world clients, including industrial, governmental, and the department's research faculty. The assignments and deliverables for these projects charted students' learning progressions to propose ideas and solutions, design, build, test, and communicate meaningful learning outcomes. In addition, the projects engaged students in a design process that was not a cookbook approach, but rather, involved hands-on experiential learning. The design process provided the flexibility needed for teams to develop unique solutions to the open-ended, real-world problems presented in course assignments and deliverables. The course assignments and deliverables were supported by coaching and scaffolding to achieve desired outcomes.

Further, faculty participants' design-based instructional practices involved cycles or repetitions of design-based activities incorporated into well-known steps or stages to achieve desired design outcomes. Negotiations determined whether or not the design results/outcomes were best outcomes, and if not, an iteration to refine ideas ensued. The faculty participants suggested iterations, or new starting points, for successful or failed attempts to achieve best outcomes. However, students' perceptions and reactions to failed attempts were often misdirected conclusions to a grade of failure in the course. It was challenging for faculty participants to convince students that design failure and course failure were not one and the same or linked conclusions. The faculty participants emphasized that failed design results were not the stopping point, but rather the beginning point that you proceed ahead with in the next iteration of the hands-on, experiential learning design process.

This iteration of design learning required the use of a course management process and tools. The course management process is much like Simon's (1996) definition of managing "complex systems…made up of a large number of parts that have many interactions…the whole is more than the sum of the parts" (p. 184). The tools for managing complex design, like open-ended, real-world problems, are comprised of productivity applications useful for tracking and communicating the status of the design process and related milestones, and deliverables. The tools used included Gantt charts, check sheets, engineering notebooks, Excel spread sheets, critical design reviews (CDR), validation reports, final written and oral reports, product demos, presentations, and design team meeting notes with product/project mentors (faculty and industry partners). The tools break down the complexity of the design process into a number of smaller, more manageable parts.

Ultimately, faculty participants' instructional practices to engage students in design thinking focused on engagement in open-ended, real-world problems that do not have right and wrong answers. This engagement included process design activities, methods, and tangible learning experiences focused on the way design teams/designers think and work. Regarding the implementation of design-based courses, introducing the design process and hands-on experiential learning are the key components. In the implementation, all project teams engaged students in the actual practice of designing and making artifacts of knowledge and were encouraged to take risks in the design process in order to come up with novel ideas and creative solutions.

Discussion

This study was guided by the overriding research question: "What can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity? This purpose was addressed through two main research questions: (a) How are faculty participant's perceptions of developing and implementing design-based courses informing 'designerly' ways of instructional preparation, and (b) How does the faculty participant's instructional practice engage student in design thinking activity?

Findings from this study aligned the attributes of design/design thinking theoretical propositions. They are displayed in the inner environment of related theoretical positions and research contributions (displayed in Figure 5).

The three primary attributes of design/design thinking are grounded in the literature—theory, process, and practice. The attributes are the teachable dimensions of design thinking activity useful for finding and solving problems. The attributes are interconnected. The theory drives process, process drives practice, and practice drives creation of artifacts as problem solving outcomes. The actions of instructors to develop and implement a design-based course is an example of designerly instructional practices grounded in the literature and aligned with design thinking attributes —theory, process, and practice.

The first theme – the distinction between design-based courses and textbook, rote learning courses is meaningful learning from thinking-outside-the-box to solve open-ended, real-world problems that have no right answers – is supported by three sub-themes. The first sub-theme focuses on the concept that designerly ways of instructional practice establish a distinction between design-based courses built on open-ended, real-world problems and traditional courses built on textbook-based problems and rote learning. The content and context of the course materials were suggested by department faculty, the instructors of record (i.e., the faculty participants), industry partners, industry standards, and interdisciplinary sources. This design-based pedagogy provides realistic exposure to designerly skills and knowledge to assemble meaning making ideas into product-solutions. The second sub-theme focuses on design-based homework and project assignments that are typically not well-defined because they are situated in open-ended, real-world problems without right answers. Students are encouraged to think deeply about design ideas in order to foster design results that achieve successful learning outcomes. The faculty participants' design-based instructional practices encourage students to push themselves and to look for novel ideas or creative solutions when solving open-ended, real-world problems with no right answers. The final sub-theme focuses on team assignments that challenged students to think deeply and to come up with creative and novel ideas. Teams tackled open-ended, real-world problem assignments as collaborators: defining problems; generating concept; testing, reflecting, and iterating solutions; employing productivity tools; engaging in group presentations; and, providing project reports (oral and written).

The second theme – connecting students' learning engagement to tangible experiences and processes of design-based instructional practice for realistic exposure to real-world problems – is supported by four sub-themes. The second theme of the study summarized evidence that connected student's learning engagement to tangible, hands-on, experiential learning and processes of designing and making artifacts to provide a more realistic exposure to real-world problems. There were multiple data points that provided evidence of design process activity that was tangible and observable. For example, students were engaged in hands-on, experiential learning to brainstorm, sketch, design, and create materials artifacts and/or reflecting-upon-actions to decide next steps – iterate and refine ideas, new product/project tests, or new starting points in response to failed attempts. The first sub-theme focuses on students' engagement in projects that were not textbook-based but rather actual real-world problems. The data provided evidence to support students' engagement in hands-on experiential learning that provided a more realistic exposure to what their real jobs might be. Projects were collected from a variety of sources including industrial, governmental, and the department's research and teaching faculty. Throughout the first semester of the course, a number of project deliverables and milestones were assigned to guide students through real-world, formal design process steps or stages. The second sub-theme, design process is not a cookbook, but rather, hands-on, experiential learning in design-based courses, exposed students to hands-on experiential design processes that were nonlinear to enable refinement of ideas if necessary. Assignments gave students the practice of making sense of things by applying well-known design process steps or stages in homework practice sets designed to expose students to open-ended, real-world, problem solving. Hands-on experiential learning engaged students in the practice of designing and making material artifacts by applying creativity, thinking-outside-the-box, and risk-taking to come up with novel ideas and potential solutions. The third sub-theme, design process for hands-on, experiential learning in iterations, gave students the experience of understanding the value of reflection and iteration to refine ideas. A design thinking instructional practice exposes students to a design process that engages them in hands-on, experiential learning design process. A design process that is hands-on, experiential and iterative provides the real-world practice of designing ways of knowing how to design, make sense of things, and improve upon the material artifacts of constructed knowledge. A design process of this type produces material artifacts that are evidence of the theoretical proposition, 'designerly' ways of knowing (Archer, 1979; Cross, 1982). The material artifacts enlarge and enrich learning prospects because they are outcomes of refining ideas and making sense of things, such as, open-ended, real-world problems that have no right answers. The fourth sub-theme, course management, summarized strategies for 'designerly' ways of instructional practice. Strategies provided guidance and support for students' teamwork and course-based design thinking activities focused on designing and making artifacts of real-world problem solutions. Strategies provided guidance for what students were actually doing in the design process. Strategies incorporated the use of productivity applications to monitor, measure, and report product development progress in stages (Gantt charts, Excel spread sheets, engineering notebooks, written and oral communication and presentations, PDR, CDRs, and weekly team meetings with the course instructor, team advisor, and industry partners (for some projects).

Overall, the study contributes to a growing research base focused on design thinking instructional practice and other gaps related to what's instructors are doing in design thinking courses. The study's findings identified three interconnected categories that explain what instructors are doing in design-based courses. Instructors are (a) embedding design/design thinking theoretical propositions in both preparation and instructional practice (*theory*), (b) guiding students through well-known steps or stages of the design process of hands-on, experiential learning in iterations useful for tackling different types of problems (*process*), and (c) establishing course management tools and techniques to support the course goals, objectives, deliverables, and student learning outcomes (*instructional practice*).

It was also learned from the study that the study's findings were related to the attributes of design/design thinking. Stated earlier, the attributes are theory, process, and instructional practice with theory driving process, process driving instructional practice. The findings are also interconnected and function in the same way as design thinking attributes. Design thinking instructional practice connect design thinking *theory* to what instructors are doing. The theory then drives the design *process* of hands-on experiential learning in iterations. And the 'designerly' ways of instructional *practice* drive the creation of artifacts as problem solving outcomes.

Limitations. The findings of this study can contribute to educators exploring design thinking research-based approaches for instructional practice. There are, however, some limitations. First, the study explored a purposive case study with a small number of participants. The two faculty participants in the case study were experienced instructors of engineering senior design capstone courses, although in two different engineering disciplines. Both participants taught design-based pedagogies developed in their respective departments over several decades to expose students to realistic open-ended, real-world, problem challenges that could be experienced in real engineering design-based jobs. The study involved two research questions that probed the two participants to obtain rich detail about their preparation, curriculum (context), and instructional practice of the engineering design-process. Perhaps future studies could consider using a larger purposive participant sample in non-design cultures. Second, the single visit to the classrooms of faculty participants, could have collected other data in addition to an understanding of the contextual focus. Other data could have been collected, such as, the lecture's time length, instructor-to-student observations and student-to-student observations for example. Collection of more classroom observation data is recommended for future study to inform subsequent semi-structured interview questions focused on what the instructor and students were doing and why.

Current Findings and What's New. The purpose of this study was to understand “What can be learned from faculty instructional practice with regard to design thinking that engages students in design thinking activity? The findings described a number of themes and related rich detail that build on the existing research base of design thinking instructional practice. The themes from the study also included several findings that are not commonly discussed in the common core knowledge supporting design thinking instructional practice. These findings build on a growing research base of design thinking instructional practice.

First, findings suggest an importance for using both internal and external resources in the course design and planning stages of a design thinking instructional practice. The connection between internal resources of the course and the problem(s) situated in the context of the external real-world are likely assumed but not explicitly identified. The faculty participants, provided rich detail about the importance of identifying both internal and external resources in the course design. Internal resources, in addition to the instructor of record (faculty participant) included the following: (a) live lectures, (b) supplemental lecture videos, (c) course website (the main communication resource between the instructor and student), (d) course syllabus and documents, (e) departmental faculty working on project teams as professional mentors, (f) engineering, science, and mathematical methodologies learned in courses that preceded the design-based course, (g) and the design process – the well-known and well-defined method of solving the problem in the department’s design-based course. External resources included (a) industry partners and industry standards, (b) connections to real-world, industry partners as judges of final products/presentations and/or project team advisors, and (c) exposure to open-ended, real-world problems. The significance of internal and external resources provides support for students' engagement in realistic, real-world problems as preparation for future real jobs. This finding contributes to the "growing" research base of the theory, process, and practice of design thinking instructional practice. Designing and making artifacts of constructed knowledge to solve problems that are not textbook based and associated with real-world problems strengthens the nature of problems selected for the course.

Although there is little literature associated with using both internal and external resources in a design thinking course design or a design thinking instructional practice, inclusion of internal and external resources connects the nature of realistic problems (that are not in textbooks) to the discipline, course, and context. The nature of designing ways of knowing how to incorporate design thinking in development of solutions for problems that are not textbook-based, requires this focus on internal and external resources. A gap exists in the literature concerning the importance of these resources in the design process. Design thinking principles and cognitive tasks should include access to internal and external resources useful for constructing problem solutions. An emphasis on connecting internal and external resources in the design process would provide more clarity for understanding meaningful learning when designing ways of knowing how to solve problems that are not text-book-based. This is evident when revisiting the literature on Simon's (1996) theoretical propositions. The science of design or design process, engages the student in internal (design process) and external resources (problems that are intellectually difficult). Simon further claimed that the process of designing and making artifacts must meet desired specifications that are "centered precisely on the interface between the inner and outer environments" (p. 113). Stated differently, designing and making artifacts is the adaptation of desired needs (internal resources) to external resources (industry partner, for example) and vice versa. Artifact making is “aimed at changing existing situations into preferred ones (p. 111). The existing situations can be internal and preferred ones external or vice versa. Design thinking is a unique approach to crafting understanding (development of internal knowledge) by creating artifacts, communicating designerly way of knowing through design process stages when solving problems not in textbooks (external environment; Archer, 1979; Buchanan, 1992; Cross, 1982).

Second, findings addressed meaningful learning and less boundaries to students’ problem-solving experiences in an open-ended, real-world, problem space. The significance of fewer boundaries suggested breaking down old disciplinary boundaries to advance problem-solving without isolation of disciplines and/or subject-domain cultures. The value of breaking down boundaries contributes to meaningful learning that is not isolated along disciplinary boundaries as opposed to knowledge that is constructed and shared across teams of individual designers in an isolated discipline, academic setting, or learning community. Design, making, and sharing constructed knowledge across individual students organized into teams was a key finding. However, there is relatively little educational research exploring teamwork theoretical propositions of design thinking.

Third, an emphasis on teamwork to design, make, and share problem-solving artifacts was a unique finding of the case study (RQ1, sub-theme 3). Theoretical propositions discuss the need for design thinking to be a part of everyone’s education (Cross, 1982; Simon, 1996); teamwork is a method of engaging students “in the same way that the sciences and the humanities are parts of everyone’s education” (Cross, 1982, p. 222). Teamwork is another approach to the recommendation to include design thinking as a part of everyone’s education. Additionally, design thinking theory and research often creates an image of design thinking as the individual’s design and human thinking process (Archer, 1979; Osorio, 2009). The faculty participant’s design teams engaged in problem solving as collaborative groups of designers. Design teams were able to grasp and evaluate learning outcomes (design results) while designing and making artifacts of constructed knowledge appropriate for the needs of real-world, open-ended problem-solving assignments. The findings of design thinking for problem-solving, communicated that teamwork was a part of everyone’s education in the design-based courses. In the study, teamwork for the academics of problem solving was presented to the learner “in the same way that the sciences and the humanities are parts of everyone’s education” (Cross, 1982, p. 222).

Regarding teamwork, the designer is grounded in the literature, but not the collaboration of designers or their teamwork from the perspectives of roles and co-dependencies on learning outcomes of the design process. The impact of collaborative teams in a design process enhancement in design thinking instructional practice. Although the steps and stages of the design process typically emphasize understanding different types of problem that the “designer” is tackling (well-defined or ill defined) (Rittel & Webber, 1973), this understanding encourages the need for more literature findings that build on design thinking in the context of the types of problems that design teams are tackling. There is an opportunity to add to design thinking literature and research findings the importance of ways in which “the participants in the design teams [students and industry partners in some case] have to actively engage in inquiry, research and design, in collaborative groups (that include higher education faculty members) to design tangible, meaningful artifacts as end products of the learning process” (Koehler & Mishra, 2005, p. 135).

Fourth, design thinking is a systematic approach useful for emphasizing a more comprehensive design process. The systematic approach makes sense of the range of tools and cognitive tasks suggested when working within a complex problem, such as an open-ended, real-world problems. This unique finding, emphasized the concept commonly known as, systems thinking.

On the topic of systems thinking, Simon (1996) claimed that the principles of a complex system, like design process and teamwork are "made up of a large number of parts that have interactions…the whole is more than the sum of the parts" (p. 183). And researchers, Arnold and Wade (2015), contributed systems thinking discourse when stating: "systems thinking consists of three kinds of things: elements, interconnections, and a function or purpose" (p. 2). The three kinds of things in systems thinking embrace thinking of things holistically. The elements are attributes or characteristics of design/design thinking (theory, process, and practice). Interconnections include disciplines across the academy as well as co-dependencies of design/design thinking attributes (theory, process, and practice). And the design thinking instructional practice function or purpose to solve problems using meaningful learning techniques, such as, hands-on, experiential learning in design process can be taught as a systems approach involving the interconnection of design/design thinking theory, process, and instructional practice. Systems thinking contributes to teamwork approaches and problem-solving because it provides "a common language and framework for sharing our specialized knowledge" (p. 2). Revisiting Simon (1996), "we must look for a common core of knowledge that can be shared by the members of all cultures" (p. 136). A system's thinking approach to design thinking instructional practice combats isolation of contributors or disciplines because knowledge sharing is an outcome of the breakdown of disciplinary boundaries.

And finally, the markers of success connect failure or failed attempts to new design process starting points. These connections of failures and new starting points promote iteration and refinement of ideas, other key elements of a design process pedagogy (instructional practice) focused on students' achievement of the desired expectancy of successful solutions. The literature does not explicitly discuss new starting points in the design process. However, the findings show that new starting points in the design process are reflective of unsuccessful design results that have failed to meet desired outcomes. When the problem space is situated in an open-ended, real world context and there are no right answers, new starting points are a critical concept in design thinking teachable doctrine for achievement of desired student learning outcomes (design results). A design thinking instructional practice inclusive of new starting points in the design process adds to the intellectual rigor of a design thinking pedagogy.

"It is widely suggested that designers possess the courage to take risks, that they are prepared to fail and that they work hard…during their design thinking activities, designers regularly (re)define and/or frame the problem, they adopt holistic thinking and they sketch, draw and model possible ideas throughout the design process" (Rodgers, 2012, p. 55). The concept of embracing design thinking risks and ambiguity has emerged in the literature in connection with problems that are not well-defined. According to Archer (2009), "it is rarely possible to determine whether or not the finished design is 'the correct,' 'the only' or 'a necessary' answer to the requirements (p. 55). The risks that design team take is judgement whether or not one answer is better or perhaps even worse than another. When outcomes do not meet expectations, new starting points are markers of successful design process stages of reflections, iterations, and refinement of ideas. A gap in the literature is this emphasis on new starting points in design process especially when engaging in hands-on, experiential learning to solve a complex problem, such as an open-ended real-world problem, interdisciplinary problem, or other problems not based on textbooks.

Pedagogical Implications. The findings from this study build on an existing design thinking research base. The interviews reinforced design thinking for instructional practice. In the existing research, design thinking is a culture for problem solving. According to Archer (1979), there is a desire to understand implications of a "balanced education for everyone" (p. 18). Designerly ways of thinking and communicating are "both different from scientific and scholarly ways of thinking and communicating, and as powerful as scientific and scholarly methods" (p. 17). Archer claims that the first thing recognized when using designerly ways of thinking and communicating is "the problem" and not the problem statement or requirements for the solution. A designerly way of thinking and communicating method begins with "sketching, drawing, construction, acting out and so on…manipulating and evaluating ideas before, during and after externalizing them (p.18). Cross (1982) elaborated on Archer's theoretical contributions with the premise that design thinking is "its own distinct intellectual culture; its own designerly things to know, ways of knowing them, and ways of finding out about them" (p. 221). The problem types are both well-defined and not well-defined (Rittel and Webber, 1973). And in the cases where problems are not well defined, such as, open-ended, real-world problems, the problem solver must go through a nonlinear design process inclusive of reflection, iteration, and new starting points. Whether the design process is taught in steps or stages, defining the problem space is the starting point for designers and design team members of a collaborative exploration with the opportunity to breakdown disciplinary boundaries for the purpose of designing and making material artifacts of constructed knowledge. The design thinking pedagogy comprises "the real subjects of the new intellectual free trade among the many cultures are our own thought processes, our process of judging, deciding, choosing, and creating" (Simon, 1996, p. 137).

Design thinking instructional practice subject-matter is aligned with a number of theoretical contributors: Simon's (1969, 1996) theory regarding curriculum and utility of cognitive activities in the creation of artifacts of knowledge; Rittel & Webber's (1973) well-defined and ill-defined problem type; Archer's (1979) designerly ways of thinking and communicating; Cross's (1982) designerly ways of knowing, things to know, and ways of knowing artifacts of problem solving; Schön's (1983) reflective practices; Kolb's (1984) experiential learning theory (ELT); Rowe's (1987) pioneering theory of design thinking terminology; Krippendorff's (1989) iteration on creation of meaning and artifacts; Buchanan's (1992) design tools (drawings, sketching, prototyping) and circular topology for solving problems that are not well-defined; Dym's (2005) divergent-convergent thinking in problem solving, and others. It is also aligned with practitioner's design process and modelling strategies focused on teaching innovation by unlocking creativity (IDEO, 2002; Stanford d. school, 2002). Design process iterations and new starting points lead to desired design results or best judgments of deciding, choosing, and creating problem solution(s) (Simon, 1996). These steps are the principles of procedures of learning and creation of knowledge in a systems approach to problem solving.

The growing research base of design thinking instructional practice "presents a robust framework for a scholarship of design teaching and learning that includes misconceptions, learning trajectories, instructional goals, and teaching strategies that instructors need to know…" (Crismond & Adams, 2012, p. 738). "The open-ended nature of design problems prevents us (the instructors) from too narrowly specifying what technologies will be needed" (Koehler and Mishra, 2009, p. 135).

The case study produced several findings useful within the context of teaching. First, educators can use the case study's findings to construct context-specific dilemmas of design thinking for pedagogy: (a) planning for what is involved in designerly ways of thinking and communicating knowledge useful for scholarly and intellectually rigorous preparation for the world beyond academia, and (b) implementing meaningful learning that breaks down old disciplinary boundaries and rote learning approaches to build up processes of sharing construction of knowledge artifacts for common understanding. Second, educators can use the findings to experiment with other ways to design and make problem solutions of contemporary society. And finally, educators can use these findings to reflect and refine their designerly instructional practices.

A design thinking pedagogy is a popular trend useful for adopting design thinking in problem-centered curricula. "The eagerness to adopt and apply these design [thinking] practices in other fields has created a sudden demand for clear and definite knowledge about design thinking" (Dorst, 2011, p. 521). Therefore, the demand to apply research-based knowledge that prepares educators for the achievement of 'designerly' instructional practice skills benefits from examples. The findings of the case study offer recommendations for educators supplementing their pedagogy with design thinking pedagogy to enrich students' engagement and learning outcomes.

In general, the basic principles of procedures of learning and creation of knowledge in a design thinking education, such as, the perceptions of the instructors in this study can be summed up as follows:

- Course design involves pedagogy focused on open-ended, real-world problems that do not have known right answers. The focus of a design thinking instructional practice shifts from methods used in standard lecture-based classes with textbooks to learning a lesson meaningfully using cognitive tools. This connects meaningful learning to students' problem-solving experiences in an open-ended, real-world, problem space. The value of breaking down boundaries contributes to meaningful learning that is not a textbook rote learning approach as well as thinking-outside-the-box to design and make knowledge artifacts and generate multiple solutions.
- Teambuilding is core to the course design. Working in teams engages students in figuring out which ideas could work best and how to help one another along the way of problem solving.
- Design process is not a cookbook learning activity. The focus of design process is not on what is already solved, but rather, hands-on, experiential learning activities for what is unsolved. These activities support students' engagement in complex problems that require them to step away from the textbook and to fully immerse themselves in the well-known steps or stages of learning-by-doing in experiential learning.
- Course management involves tools problem designers need for the circular process of design thinking. The circular process or nonlinear process of design thinking engages problem solvers in hands-on, experiential learning. The process describes the design process of problem solving as a "conceptual framework to uncover, confirm, or qualify the basic processes or concepts" (Miles et al., 2020, p. 27).

- Iteration and reflection foster achievement strategies for successful creative ideas and problem solutions. Markers of success involve the outcomes of iteration and reflection for refinement of creative ideas and problem solutions.
- Failure is another marker of success. Failure is the beginning of new starting points whether caused by successes or failed attempts to achieve desired targets and specifications. The new starting points are strategic attributes of hands-on, experiential learning. Failure, therefore, is the marker of a successful new start in the design process of complex, problem solving. Failure is embedded in circular (nonlinear) system's thinking when designing and making artifacts of constructed knowledge. New starting points contribute to learning with understanding from creation of artifacts that are "our own thought processes, our process of judging, deciding, choosing, and creating" (Simon, 1996, p. 138).
- Open-ended, real-world problems in academic setting are opportunities for meaningful learning based on design thinking in subject-matter pedagogy. Complex problems of this nature invite an intellectual free trade of knowledge among students and across disciplinary boundaries.

Future Research. Future research may focus on continuing the research on design thinking in pedagogy, engaging in case studies across the academy's design and non-design cultures. The purpose of these case studies would be to continue building pedagogy useful for educators solving complex problems using a systems approach. Design thinking for instructional practice, as a systems approach to solving complex problems, has a place in teaching and learning approaches in an era of explosive innovation and global issues. The Internet of Things (IoT) and the COVID-19 pandemic are examples of global change agents to have affected the learning dynamics, social contract, and academically rigorous teaching schemas of how and why we choose to participate in the growing research on pedagogy for complex problem solving in education. Interdisciplinary pedagogy and research could experiment with the growing opportunities of design thinking for instructional practice because future unknown problems are emergent, open-ended, problems of the real world. Future research could also consider development of a descriptive framework for design thinking instructional practice useful across the academy.

Overall Conclusions

The literature review and case study manuscripts in this dissertation offer answers and findings regarding what can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity.

The literature review manuscript summarizes three major findings: (a) design thinking attributes are critical to design thinking activity, (b) design thinking is not easily deconstructed into specific academic disciplines but rather embedded in problem solving to design and make artifacts of constructed knowledge, especially useful for open-ended, real-world problems that typically cross disciplinary boundaries, and (c) the design thinking learner engages in episodes or cognitive intellectual activity events focused on learning-by-doing, creative thinking, and experiential learning.

The literature review manuscript revealed informative theoretical contributions used in a wide range of design thinking applications in the academic realm, business realm, education, problem-solving approaches, engineering design, multi- and transdisciplinary problems and courses, medicine, politics, COVID-19 health and safety, and many others. There are also a number of engagement learning approaches that incorporate design thinking attributes: active learning, discovery learning, and hands-on experiential learning. Design thinking attributes are embedded in popular design thinking models, such as, The Institute of Design at Stanford (d.school), IDEO design consultancy, and the technology, pedagogy, and content knowledge framework (TPACK) for effective teaching with technology "based on Shulman's (1986, 1987) construct of pedagogical content knowledge (PCK)" (Koehler et al., 2013, p. 13).

Other theoretical contributions of the literature review manuscript focused on emergent content knowledge and artifacts of constructed knowledge as evident in theoretical contributions supporting learning with understanding. “Every teacher knows that there is a profound difference between a student learning a lesson by rote and learning it with understanding, or meaningfully” (Simon, 1996, p. 101). Emergent knowledge is “understood, rather, to ‘emerge’ as we, as human beings, participate in the [real-] world” (Osberg & Biestra, 2008, p. 313). Constructed knowledge artifacts are designed by everyone “who devises courses of action aimed at changing existing situations into preferred ones” (Simon, 1996, p. 111).

The case study manuscript involved a small, purposive sample of faculty participants from a large, public research-intensive university in the southeastern region of the United States. The context of the case study involved design-based courses that integrate open-ended, real-world problems that do not have right answers into lesson plans and student learning objectives and goals. The data analyses were a triangulation of two semi-structured interviews conducted with the faculty participants and summative document content of materials supporting their syllabi and course materials. The study’s thematic findings are not tied to engineering but rather course design, design process, and course management, suggesting utility for everyone as designers of constructed knowledge artifacts across the academe.

Several of the case study findings are also gaps or examples of very little existing design thinking literature uncovered in the search. First, the significance of internal and external resources for student’s engagement in realistic, real-world problems for designerly ways of thinking about and communicating complex problem-solving approaches. Second, the value of breaking down boundaries contributes to “learning with understanding, or meaningfully” (Simon, 1996, p. 101) that is not isolated along disciplinary boundaries but rather “a common core of knowledge that can be shared by the members of all cultures” (p. 136). Third, an emphasis on teamwork to design, make, and share problem-solving artifacts for “importing and exporting from one intellectual discipline to another ideas…in organized cooperation—solves problems and achieves goals in outer environments of great complexity" (Simon, 1996, p. 138). Fourth, design thinking is a systematic approach that consists of elements, interconnections, and intellectually tough teachable schemes of design process for solving complex problems (Arnold & Wade, 2015; Simon, 1996). And finally, the markers of success demonstrate that failures or failed design thinking attempts connect to new design/design thinking starting points.

Design thinking "is a practical form of inquiry in so far as it is concerned with making and a certain commonplace usefulness" (Rowe, 1987, p. 1). The commonplace usefulness of design thinking is its theory, process, and process - the attributes of design thinking instructional practices. According to Simon (1996), the practice of teaching subject matter that makes connections to designing and making artifacts of constructed knowledge should be observable in practice. Understanding the interconnection of these attributes provides clarity for understanding design thinking activity.

Design thinking theory to practice with a process bridge provides instructional practice tools useful for successful design thinking activity in instruction. However, theory to process without the practice bridge or process to practice without the theory bridge lacks the interconnection of all three design thinking attributes. The strength of interconnecting the three attributes broadens understanding and application of design thinking activity in classroom instruction across the academy. "University work has often been 'too theoretical' in ways that leave teachers bereft of specific tools to use in the classroom" (Darling-Hammond, 2006, p. 308). Design/design thinking attributes contribute to designer's actions in the following ways:

1 Theory: knowledge of what students will learn and how to develop design thinking knowledge, tools, & skills; bridge between process and practice

2 Process: knowledge of how to design and make artifacts, inclusive of knowledge of curriculum materials, defining problems, exploration of ideas, group work, iteration, brainstorming, reflection-on-actions, synthesis, "satisficing," higher-order cognition (analysis, creation, evaluation); nonlinear; bridge between theory and practice.

3 Practice: knowledge of teaching subject matter and design and/or design thinking that interconnects design thinking practice to theory and process; communication of findings and contributions; experience-based knowledge makes formal learning practical.

The literature review manuscript and case study manuscript together can contribute to design process and instructional practice attributes of design thinking. Learners engage in design thinking activity through instructional practice guidance through the steps or stages of the design process. These design thinking attributes can be traced forward from Simon's (1969, 1996) seminal work, *The Sciences of the Artificial*, to present day 21st century design thinking theorists, researchers, and practitioners. Theoretical contributors include: Rittel & Webber (1973), Archer (1979), Schön (1983), Rowe (1987), Krippendorff (1989), Buchanan (1992), Cross (1982, 2001, 2007), and many others.

Design process and instructional practice attributes in the literature review and case study manuscripts included: (a) problems space and revised problem space models (Middleton, 2005; Newell & Simon, 1972), (b) design thinking models (Kelley, 2005; Oxman, 2017) (c) cognitive activities, practices, and rigor for using design thinking to deal with complex problems (Hess et al., 2009; Kimbell, 2009, 2011; Rowe, 1987) , (d) academic discourse of designerly thinking (Cross, 2001, 2007; Johansson-Sköldberg et al., 2013), (e) design thinking pedagogy (Crismond

& Adams, 2012; Koh et al., 2015; Luka, 2014), (f) the events or episodes of divergent-convergent thinking and learning-by-doing for learning with understanding (Dewey, 1958; Dym, 2005; Simon, 1996), and looking for "tangible record (observable) of a variety of [teaching] schemes.… [and] a common core of knowledge that can be shared by the members of all cultures," both design and non-design academic cultures (Simon, 1996, p. 136).

In summary, what can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity involves design thinking attributes. The design thinking attributes are reinforced by the case study findings summarizing design thinking instructional practice - course design, design process, and course management. Based on these findings, this dissertation adds clarity of understanding design thinking preparation, context, and instructional practice. It also contributes to pedagogy that promotes high student-centered engagement for highly productive learning with understanding. Overall, the findings recommend that design thinking instructional practice is a pedagogy for inclusion of everyone in designing and making artifacts of constructed knowledge, useful for fields across the academe, not just engineers and other traditional designers.

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List of Appendices

Appendix A – Faculty Recruitment Email

Design Thinking Instructional Practice Research Study

Email Subject Line: Design Thinking Instructional Practice Research Study

Dear [Subject Name],

Hello. My name is Joanie Banks-Hunt, and I am a doctoral candidate in Curriculum & Instruction with an emphasis in Educational Psychology and Engineering Education.

I am combining a multi-decade, Silicon Valley high tech career in electrical engineering product design and fifteen-year teaching career in mathematics and engineering instruction for high school students into a "Design Thinking" qualitative research study, VT IRB #19-1011, in partial fulfillment of a Doctor of Philosophy degree. The purpose of the study is to understand, "What can be learned from faculty instructional practice with regard to design thinking that engages students in design thinking activity? The purpose is to explore faculty participants' understanding and implementation of this question. This purpose will be pursued through the use of semi-structured interviews and course documents (such as the syllabus, lecture slides, and course handouts).

Eligibility criteria for the study includes being an instructor of: (a) undergraduate design-based classes, (b) Spring Semester 2020 course offering in the VT Class Timetable, and (c) the VT design culture (engineering disciplines, architecture, design thinking curricula, industrial design, and etc.).

The study is designed for minimal impact on your professional time. The study requests a copy of your course syllabus and presentation slides for at least one lecture. Data will be collected using semi-structured interviews and document content analysis (syllabus, slides, 1 lesson plan, assignments, etc.). Your volunteer participation is needed for up to 4 weeks. It will involve: (1) completion of a short, online demographics survey (see link below), (2) your verbal consent to participate in the study at the first face-to-face interview, (3) one scheduled, unobtrusive classroom observations (no interruption to what's going on in the classroom and no communication with students), and (4) two semi-structured, recorded, interviews expected to last up to 90-minutes each. The research study is expected to begin Spring Semester 2020. Participants can withdraw from the study at any time without providing an explanation.

If you have any questions about this study, please feel free to contact me at joaniebh@vt.edu or (650) 269-3444.

Faculty Demographics survey link name: Faculty Demographics Survey_Banks-Hunt Design Thinking Study_February 2020

Sincerely,
Joanie Banks-Hunt
Ph.D. Candidate, Virginia Tech
Curriculum & Instruction
Emphasis: Educational Psychology
Graduate Certificates: Education Cognition, Engineering Education

Appendix B – Demographics Survey

Start of Block: Default Question Block

Q1 Course name (select from list).

- o BSE
- o ME
- o ARCH
- o Other ________________________

Q2 Gender

- o Male
- o Female
- o Skip (decline request)

Q3 Ethnicity

____

Q4 Age

____

Q5 Years teaching overall:

____

Q6 Years teaching design-based classes and email address:

____

Q7 Design-based course content (check all that apply)

- Biological Systems Engineering
- Design Thinking Models
- Design Thinking Theory
- Mechanical Engineering
- Problem-Based Learning
- Curriculum: Senior Design Capstone Course
- Other ____________________

Q8 Teaching Background (prior courses taught). Select all that apply:

- ☐ Biology ____
- ☐ Engineering ____
- ☐ Biological Systems Engineering (non-design-based course) __________________
- ☐ Mechanical Engineering (non-design-based course) _________________________
- ☐ Other (please specify design and/or non-design-based course)________________

Q9 Number of students currently enrolled in your design-based course______________________

Q10 Required course for major?

- Yes
- Not prerequisite. Open to multiple majors ____
- No

End of Block: Default Question Block

Appendix C – Semi-structured Interview Guide #1

Interview Script #1: Perceptions of Preparation and Practice

Verbal Consent Script. Interview #1

Interviewer (co-PI/researcher – Ph.D. candidate): Hello. How's your day going?

The activity. The research study that you are participating in is my partial fulfillment of requirements for the degree of Doctor of Philosophy in the discipline of Education Curriculum and Instruction.
Purpose. The purpose of the study is to understand the principal research question, "What can be learned from faculty's instructional practice with regard to design thinking that engages students in design thinking activity?
Procedure. The study will be conducted in three phases.

- Phase 1 is the first of two semi-structured interviews (Interview #1: Perceptions of Preparation and Practice).
- Phase 2 is the second semi-structured interview (Interview #2: Reflections on Practice).
- Phase 3 is data analysis and comprises document content analysis, triangulation of two transcribed interviews, and member checking. Document content analysis will focus on the instructional materials you have provided (syllabus, slides, etc.). This analysis will span phases 1 and 2.
- An unobtrusive, non-participatory, classroom observation will be conducted between interviews 1 and 2. The purpose of the classroom observation is not to collect data, but rather to provide practice-based context that will be used in interview #2.
- Transcription of interviews. Semi-structured interviews will be recorded and transcribed by a secure transcription service, Rev.com.
- Member checking will be used after semi-structured interviews have been transcribed. Member checking of transcribed interviews is a tool to assist in ensuring that your perceptions have been accurately stated and recorded. The process of checking in with you for edits enhances the study's rigor and trustworthiness.
- Triangulation data analysis follows member checking and document content analysis. It explores language and thematic coding across the 2 transcribed interviews (semi-structured interviews #1 and #2) and the instructional materials that you have provided.
- After the 3 phases of data collection I will organize the findings and prepare results statements and conclusions.

Volunteer Participation Statement. And lastly, I want to iterate that your participation is completely voluntary and is without compensation. As a research study participant, you can withdraw from the study at any time without providing an explanation. If you choose to withdraw from the study, your demographics survey information, instructional materials, and interviews will remain private and confidential.
Do you have any questions?
Interviewee: __________
Verbal consent procedure. The following verbal consent procedure allows you to play a collaborative role in the decision regarding your participation in the study.

- Do I have your permission to waive written consent with your verbal consent on this recorded conversation? If yes, please respond, "yes" or "ok" to affirm your verbal consent.

Interviewee: __________

Interviewer: I would like to record the interview in order to transcribe your responses later. Is this ok?

Interviewee (response: _________

Interviewer: Thank you. I am starting the recording now (at time)___________

(With verbal consent, recording begins)

- ☐ You may stop the interview at any point if you feel it is necessary.
- ☐ I want to assure you that your responses will be kept confidential. At this time, I have chosen the pseudonym, [e.g., FP72, FP20], to identify your verbal contributions to the findings of this study. Do I have your consent to use this suggested pseudonym?

Interviewee: ___________________

Interviewer: Would you like a copy of the explanation of the study and verbal consent?

Interviewee: ___________________

Interviewer: Thank you again, [*Pseudonym*], for consenting to participate in this study.
I am interested in understanding an overriding research question, "What can be learned from faculty instructional practice with regard to design thinking that engages students in design thinking activity?"

Interview Guide #1: Perceptions of Preparation and Practice

Interviewer: I will now begin asking a number of interview questions. Please stop me to ask for clarification at any time. Let's get started*!*

Describe your design-based course	1. What is a design-based course? 2. Can you talk about how you came to teach this design-based course? **3.** What are your goals for the course? 4. What are the key understandings, skills, or attitudes you want students to take away from the class? 5. What are the markers for success in taking your course? **6.** How and when do you know if you have been successful? 7. Can you talk about how you designed the course? 8. Can you talk me through your syllabus, focusing on the activities and assessments for the class? 9. Can you talk about what you see as the core or essential instructional aspects of the class? 10. What are the challenges to designing and teaching a design-based course? 11. How did you learn to teach a design-based course? 12. How does teaching your design-based course differ from teaching a regular non-design-based course? 13. Are there specific differences between your design-based course and non-design-based course? 14. What are the roles of your GAs in your design-based course? 15. How do you prepare your GAs to assist with your design-based course? 16. Is the role of your GAs different in your design-based course versus your non-design-based course?

Appendix D – Semi-structured Interview Guide #2

Interview Script #2: Reflections on Practice

Verbal Consent Script. Interview #2

Interviewer (co-PI/researcher – Ph.D. candidate): Hello. Welcome Back, [FPxx]

The activity. Before we begin, I would like to review this research activity. The research study that you are participating in is my partial fulfillment of requirements for the degree of Doctor of Philosophy in the discipline of Education Curriculum and Instruction.
Purpose. The purpose of the study is to understand the principal research question, "What can be learned from faculty's instructional practice with regard to design thinking that engages students in design thinking activity?
Procedure. The study is being conducted in three phases.

- Phase 1 is the first of two semi-structured interviews (Interview #1: Perceptions of Preparation and Practice).
- Phase 2 is the second semi-structured interview (Interview #2: Reflections on Practice).
- Phase 3 is data analysis and comprises document content analysis, triangulation of two transcribed interviews, and member checking. Document content analysis will focus on the instructional materials you have provided (syllabus, slides, etc.). This analysis will span phases 1 and 2.
- An unobtrusive, non-participatory, classroom observation will be conducted between interviews 1 and 2. The purpose of the classroom observation is not to collect data, but rather to provide practice-based context that will be used in interview #2.
- Transcription of interviews. Semi-structured interviews will be recorded and transcribed by a secure transcription service, Rev.com.
- Member checking will be used after semi-structured interviews have been transcribed. Member checking of transcribed interviews is a tool to assist in ensuring that your perceptions have been accurately stated and recorded. The process of checking in with you for edits enhances the study's rigor and trustworthiness.
- Triangulation data analysis follows member checking and document content analysis. It explores language and thematic coding across the 2 transcribed interviews (semi-structured interviews #1 and #2) and the instructional materials that you have provided.
- After the 3 phases of data collection I will organize the findings and prepare results statements and conclusions.

Volunteer Participation Statement. And lastly, I want to iterate that your participation is completely voluntary and is without compensation. As a research study participant, you can withdraw from the study at any time without providing an explanation. If you choose to withdraw from the study, your demographics survey information, instructional materials, and interviews will remain private and confidential.
Do you have any questions?
Interviewee: __________

Verbal consent procedure. The following verbal consent procedure allows you to play a collaborative role in the decision regarding your participation in the study.

- Do I have your permission to waive written consent with your verbal consent on this recorded conversation? If yes, please respond, "yes" or “ok” to affirm your verbal consent.

Interviewee: __________

Interviewer: Thank you. I am starting the recording now (at time)___________

(With verbal consent, recording begins)

- ☐ You may stop the interview at any point if you feel it is necessary.
- ☐ I want to assure you that your responses will be kept confidential. Today’s interview is with pseudonym, [e.g., FP_{A_alpha}, FP_{O_omega}].

Interviewer: Would you like a copy of the explanation of the study and verbal consent?

Interviewee: ___________________

Interviewer: Thank you again, [*Pseudonym*], for consenting to participate in this study. I am interested in understanding an overriding research question, “What can be learned from faculty instructional practice with regard to design thinking that engages students in design thinking activity?”

- **(*Introduction to post-observation interview)***

For this interview, we will focus on a lesson plan/classroom observation. I observed your classroom not for data collection, but rather, to gain an understanding of the practice-based context. I’d like to go back to the class where you… [describe the nature of the class]

Interview Guide #2: Reflections on Practice

Interviewer: I will now begin asking a number of interview questions. Please stop me to ask for clarification at any time. Let's get started*!*

Tell me about your perceptions of design thinking process and practice in-class activity

1. How did your class go?
2. How would you describe your teaching practices in the class?
3. Were the goals you set for the class met? How?
4. Can you talk me through your class? What you did and why?
5. Is how you've taught this class different from your normal non-design-based course?
6. What went well and what were the challenges?
7. What might you do differently?
8. As you look forward to this semester, what's next? How different is your spring semester compared to your fall semester?
9. How do you design and grade student projects?
10. What does success look like for students completing your projects?
11. How do you know when you've been successful in the class or course?
12. What do you see as the potential for design-based classes?
13. What changes have you made to your course over time? Why?
14. What advice would you give to faculty who are new to teaching a design-based course?

Interviewer:
Thank you again for your participation. If you have any questions or think of anything else you want to share please feel free to contact me.

Appendix E – Virginia Tech IRB Approval

Virginia Tech Institution Review Board Approval

VIRGINIA TECH.

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: March 17, 2020

TO: Peter Doolittle, Joan Maria Banks-Hunt

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires October 29, 2024)

PROTOCOL TITLE: Design Thinking Instructional Practice: Descriptive Study

IRB NUMBER: **19-1011**

Effective March 17, 2020, the Virginia Tech Human Research Protection Program (HRPP) and Institutional Review Board (IRB) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104(d) category(ies) 1.

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit a new request to the IRB for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As: **Exempt, under 45 CFR 46.104(d) category(ies) 1**
Protocol Determination Date: **March 17, 2020**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Table 3. Alignment of Research Questions and Data Sources

Research Questions	Data Sources		
Overriding RQ **What can be learned from faculty perceptions of instructional design and practice with regard to design thinking that engages students in design thinking activity?**	Documentation (syllabus, assignments, course materials, handouts)	Semi-Structured Interview #1	Semi-Structured Interview #2
RQ1 **How are faculty participants' perceptions of developing and implementing design-based courses informing 'designerly' ways of instructional practice?**		primary	secondary
RQ2 **How do faculty perceive that their instructional practices engage students in design thinking activities?**		secondary	primary

Table 4. Acronyms, Definitions, and Keywords

Dissertation: Exploring Design Thinking for Instructional Practice	
Study Design	Qualitative
Primary Objectives	To explore faculty participants' understanding and perceptions of the design and implementation of design thinking instructional practice
Secondary Objectives	*(a)* Design Thinking Instructional Practice: Theory to Artifacts (Manuscript 1) *(b)* Design Thinking Instructional Practice: Exploring Faculty's Preparation, Context, and Instructional Practice (Manuscript 2)
Study Population	Small purposive sample of undergraduate faculty members teaching design-based courses at a research-intensive university in southeastern US.
Sample Size	2 qualified faculty participants
Research Intervention(s)/Investigational Agent(s)	The study includes a demographics survey and semi-structured interviews.
Study Duration for Individual Participants	The participants will be involved for one semester (Spring 2020). The researcher will conduct two semi-structured interviews focused on design thinking perceptions and practice. Semi-structured interviews are expected to last up to 90-minutes. Interview #1: Perceptions of Practice and Preparation. The initial information gathering conversation with the faculty participants. The purpose of the first semi-structured interview is to explore the faculty participant's perceptions of preparation and practice for teaching a design-based course. Interview #2: Reflections on Practice. The purpose of the second semi-structured interview is to explore the faculty participant's reflections on course lesson plans as well as the specific lesson plan observed by the researcher.
Key Terms & Definitions	
Academic Respectability	Calls for subject matter that is intellectually tough, analytic, formalizable, and teachable" (Simon, 1996, p. 112).
Artifacts	"Not apart from nature, adapted to human goals and purposes …They are what they are in order to satisfy our desire to fly or to eat well" (p. 3). Mental images and physical symbols and materials. Discussed in Herbert Simon's (1996) thesis on artificial science, artifacts are constructed knowledge and/or materials.

Artifact Making	What the designer learns, the constructed materials and knowledge.
*Capstone design course	"The pinnacle course of undergraduate engineering education; students are divided into teams to undertake different design projects that provide them with unique opportunity to apply knowledge and technical skills" (Platanitis, G., Pop-Iliev, R., & Nokleby, S. (2009, January). Implementation and effect of rubrics in capstone design courses. In ASME 2009 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. 399-407). American Society of Mechanical Engineers Digital Collection.)
Complex Systems	One made up of a large number of parts that have many interconnections (Simon, 1996, p. 184)
Complex design processes	"A body of empirical phenomena to which the student of design has had to be explicit about what is involved in creating a design" (Simon, 1996,p. 137).
Design	A process of actions to put together or relate ideas and/or objects in order to create a whole which achieves a certain purpose (C.W. Churchman, 1987); an interdisciplinary domain that employs approaches, tools, and thinking skills that help designers devise "courses of action aimed at changing existing situations into preferred ones" (Simon, 1996, p. 111); "how things ought to be, with devising artifacts to attain goals" (p. 114)
Design Attributes	The alternatives or characteristics of design that organize design thinking activity: theory, process, and practice.
*Design Culture	"Its own distinct intellectual culture; its own designerly 'things to know, ways of knowing them, and ways of finding out about them'" (Cross, 1999 citing Archer, Baynes, and Langon, Design in General Education, (London, UK: Royal College of Art, 1979).
*Design Thinking	Many definitions for this terminology, such as: (a) viewed as a constructivist approach that enables students, through design projects, to make learning process tangible (Lin, Hong, & Chai, 2019, p. 1), (b) cognitive activity or strategy, and (b)

	suggests the cognitive processes of design work, inclusive of thinking skills and design attributes (theory, process, and practice) designers use to create new artifacts of ideas, knowledge, and things to solve problems in practice (Cross, 1982, 2001; Rowe, 1987; Simon, 1996). It is higher-level cognitive activity embedded in knowledge-building activities for artifact making (products, knowledge, materials (Lin, Hong, Chai, 2019, p.7).
*Design-based course	In this study these design courses involve project-based learning that has "emerged as a means for students to be exposed to some flavor of what engineers actually do while enjoying an experience where they could learn the basic elements of the design process by doing real-world design projects" (Dym et al., 2005, P. 103).
"Designerly Ways of Knowing"	"Things to know, ways of knowing them, and ways of findings out about them" that are specific to design activity focused on problem-solutions typically of an ill-defined nature (Cross, 1982). This focus is distinct from the more usually-recognized scientific and scholarly ways of knowing.
Emergent Content Knowledge	Because of "increased mobility, the world-wide web, and instant information, teachers and students find themselves in previously unknown place, context, and situations" (Luka, 2014, p. 63); complexities for attainment of desired knowledge. According to Simon (1996), emergent knowledge is"the test that something has been discovered is that something new has emerged that could not have been predicted with predicted with certainty and that the new thing has vale or interest of some kind" (p. 106).
Ill-defined problems	Problems of this type are "elusive…akin to that of 'malignant' (in contrast to 'benign') or 'vicious' (like a circle) or 'tricky' (like a leprechaun) or 'aggressive' (like a lion, in contrast to the docility of lamb)" (Rittel and Webber, 1973, p. 100)
*Instructional Practice	What teachers are doing in design thinking pedagogy; curricular examples

Knowledge Construction	The learning outcomes when designing and making artifacts or what is learned from the design process.
Learning	"Any change in a system that produces a more or less permanent change in its capacity for adapting to its environment" (Simon, 1996, p. 100).
Learning "by doing"	"By solving a problem several times in succession, gradually acquires an efficient and general strategy" (p. 105)
Learning by Rote	"It can be regurgitated more or less literally, but it cannot be used as a cognitive tool" (Simon, 1996, p. 101)
Learning with Understanding	Meaningfully (p. 101).
Member Checking	Member checking, is used "to determine the accuracy of the qualitative findings, such as specific descriptions" (Creswell, 2009, p. 191).
Open-ended problems	Problems that are not well-defined or ill-defined; nature of the problem is more complex, fuzzy, no right answers, such as real-world situations
Rote Learning	Retention: "the ability to remember material at some later time in much the same way it was presented during instruction" (Mayer, 2002, p. 226) Transfer: "the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter" (Mayer & Wittrock, 1996)
Semi-structured Interview	Open-ended questions
System	A collection of interacting pieces, "more than the sum of its parts" (Simon, 1996, p.)
Theory	"…tells us how to generate effective problem representations" (Simon, 1996, p. 131).
Thick Descriptions	According to Denzin (1989), there are 4 characteristics of thick description: (1) to give context of an act, (2) to organize the action into its intentions and meanings, (3) to trace the act's evolutions and development, and (4) to present the action in a textual form for interpretation (Denzin, 1989; Thompson, 2001).
Well-defined problems	Problems of this type are definable and may have clear solutions that are findable (Rittel & Webber, 1973, p. 100).