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What Is Design Thinking and Why Is It Important?

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Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign. Several characteristics (e.g., visualization, creativity) that a good design thinker should possess have been identified from the literature. The primary purpose of this article is to summarize and synthesize the research on design thinking to (a) better understand its characteristics and processes, as well as the differences between novice and expert design thinkers, and (b) apply the findings from the literature regarding the application of design thinking to our educational system. The authors' overarching goal is to identify the features and characteristics of design thinking and discuss its importance in promoting students' problem-solving skills in the 21st century.

Keywords: design thinking, design process, expertise, expert and novice.

Being successful in today's highly technological and globally competitive world requires a person to develop and use a different set of skills than were needed before (Shute & Becker, 2010). One of these skills is called design thinking. Design has been widely considered to be the central or distinguishing activity of engineering (Simon, 1996). It has also been said that engineering programs should graduate engineers who can design effective solutions to meet social needs (Evans, McNeill, & Beakley, 1990). Like problem solving, design is a natural and ubiquitous human activity. Needs and dissatisfaction with the current state combined with a determination that some action must be taken to solve the problem is the start of a design process. In this view, many scientists have been designing and acting as designers throughout their careers, albeit often not being aware of or recognizing that they are performing in a design process (Braha & Maimon, 1997).

According to Braha and Maimon (1997), engineering lacks sufficient scientific foundations. Historically, engineering curricula have been based on models that are devoted to basic science, where students apply scientific principles to technological problems. However, this practice produces engineering graduates who were perceived by industry and academia as being unable to practice in industry. This concern caused leaders of engineering departments and colleges to recognize the intellectual complexities and resources demanded to support good design education (Todd & Magleby, 2004). This awareness has resulted in the improvement of existing courses to include industry-sponsored projects where companies provide real problems along with real-world expertise (Bright, 1994; Dutson, Todd, Magleby, & Sorensen, 1997).

Design thinking has also started to receive increased attention in business settings. This is because the design of products and services is a major component of business competitiveness, to the extent that many known companies have committed themselves to becoming design leaders (Dunne & Martin, 2006). And although design thinking has become an integral part of the design and engineering fields as well as business, it can also have a positive influence on 21st century education across disciplines because it involves creative thinking in generating solutions for problems. That is, in academic environments, students are required to read critically, think and reason logically, and solve complex problems (Rotherham & Willingham, 2009). Thus, to help students succeed in this interconnected, digital world we live in, educators should support students in developing and honing 21st-century skills (e.g., design thinking, systems thinking, and teamwork skills) that enhance their problem-solving skills and prepare them for college and career (Rotherham & Willingham, 2009; Shute & Torres, 2012).

These skills are consistent with the theoretical traditions of situated cognition (Lave & Wenger, 1991), developmental theories (Piaget, 1972), and constructivism (Bruner, 1990). What's new is the growing extent to which individual and collective success is seen as depending on having such skills. In addition to business settings, design thinking has received a lot of attention in engineering, architecture, and design majors in universities because it can change how people learn and solve problems (e.g., Dym, Agogino, Eris, Frey, & Leifer, 2005; Fricke, 1999; Nagai & Nagouchi, 2003). The topic of expertise in design has also been receiving increasing attention in design research. In support of these claims, consider the large number of research articles published on the topic of design thinking (e.g., Do & Gross, 2001; Goldschmidt & Weil, 1998; Owen, 2007; Stempfle & Badke-Schaube, 2002; Tang & Gero, 2001). Among these research papers, there are studies of expert or experienced designers and comparisons of the processes of novice versus expert designers (e.g., Cross & Cross, 1998; Ericsson & Smith, 1991; Ho, 2001). Within this large body of design thinking research, experimental and quasi-experimental studies are lacking. Most, if not all of the studies are qualitative.

Goals and Focus

The dual aims of this article are to (a) summarize findings from the literature of design thinking to gain better understanding of its characteristics, processes, and differences between novice and expert design thinkers and (b) apply the findings from the literature regarding design thinking to our educational system. Our overarching goal is to identify the features and characteristics of design thinking and show its importance in promoting students' problem-solving skills needed to succeed in the 21st century. The major questions addressed in this review include (a) What are the characteristics of design thinking, (b) what are the differences between a novice and an expert design thinker, and (c) why is design thinking important?

TABLE 1
Databases used in searching for articles

Database and Web sites	Description
ERIC	A database that provides extensive access to education-related literature from the following two printed journals: *Resources in Education* (*RIE*) and *Current Index to Journals in Education* (*CIJE*).
JSTOR	A database of back issues of core journals in the humanities, social sciences, and sciences. The gap between the most recently published issue of any journal and the date of the most recent issue available in JSTOR is from 2 to 5 years.
ScienceDirect	One of the largest online collections of published scientific research. It is operated by the publisher Elsevier and contains nearly 10 million articles from over 2,500 journals and over 6,000 e-books, reference works, book series, and handbooks.
IEEE Xplore	A database that indexes, abstracts, and provides full-text for articles and papers on computer science, electrical engineering, and electronics. The database mainly covers material from the Institute of Electrical and Electronics Engineers (IEEE) and the Institution of Engineering and Technology (IET). The IEEE Xplore database contains over 2 million records.
Google Scholar	Google Scholar was employed to search for and acquire specific references. Google Scholar is a Web site providing peer-reviewed papers, theses, books, abstracts, and articles from academic publishers, professional societies, preprint repositories, universities, and other scholarly organizations.

Method

Many articles in the design thinking literature were identified and then collected. Table 1 lists and describes the online databases and Web sites that were employed in this search-collection effort. The focus of the search was to access full-text documents using various search terms or keywords such as *design thinking, design cognition, design behavior, design studying, design reasoning, design process, thinking of design, visual thinking*, and *prototyping*. The search was not limited to a particular date range or experimental studies. However, slight preference was given to more recent research. In all, approximately 150 documents were collected. From this set, a total of more than 45 documents met the criteria for inclusion in the literature review. The inclusion criteria consisted of topical relevancy of documents to the research questions in this article (e.g., design thinking characteristics and processes, novice vs. expert design thinker, and the importance of design thinking). Both experimental and nonexperimental studies were included in this article.

Literature Review

Many authors have written about the nature of and different processes underlying the design thinking process (e.g., Liu, 1996; Owen, 2007; Stempfle & Badke-Schaube, 2002). We now present our review of the literature of this area, starting with a description of the nature of design thinking, its characteristics, and processes. Next, we present literature regarding expertise, expert versus novice design thinkers, and expertise in design. We then present our design thinking model adapted from Shute and Torres (2012). Finally, we discuss the findings from the literature, showing the importance of design thinking and providing suggestions for future research.

Nature of Design Thinking

In many fields, knowledge is generated and accumulated through action (i.e., doing something and evaluating the results). That is, knowledge is used to produce work, and work is evaluated to produce knowledge. Creative people tend to work in two different ways: either as finders or as makers (Owen, 2007). Finders demonstrate their creativity through discovery. They are driven to understand and to find explanations for phenomena not well understood. Makers are equally creative, but they are driven to synthesize what they know in new constructions, arrangements, patterns, compositions, and concepts. Given the fundamental process differences between how finders and makers think and work, other factors might similarly reveal differences among professional fields and therefore help to define the nature of design thinking. One such factor is the content with which a field works.

A conceptual map can be drawn to represent both content and process factors (Figure 1). Two axes define the map. Separating the map into left and right halves is an analytic/synthetic axis that classifies fields by process (i.e., the way they work). Fields on the left side of the axis are more concerned with finding or discovering; fields on the right are concerned with making and inventing. A symbolic/real axis divides the map into halves vertically. Fields in the upper half of the map are more concerned with the abstract, symbolic world, as well as the institutions, policies, and language tools that enable people to manipulate information, communicate, and live together. Fields in the lower half are concerned with the real world and the artifacts and systems necessary for managing the physical environment (Owen, 2007).

Four quadrants result from this division. The first is *analytic/symbolic*, which includes fields like science that are heavily analytic in their use of process and their content is more symbolic than real in that subject matter is usually abstracted in its analyses. The second quadrant is *synthetic/symbolic*, which includes fields that are concerned extensively with the symbolic content and synthetic processes. For instance, law falls in this quadrant because it is concerned with the symbolic content of policies and social relationships, and most of its disciplines are concerned with the creation of laws. The third quadrant is *analytic/real*, which on the content scale involves reality and on the process scale is strongly analytic. Medicine, for example, falls into this quadrant because it is highly concerned with real problems of human health and diagnostic processes are its primary focus. The fourth is *synthetic/real*, which involves fields, such as design, that include synthesis processes and real content (Owen, 2007).

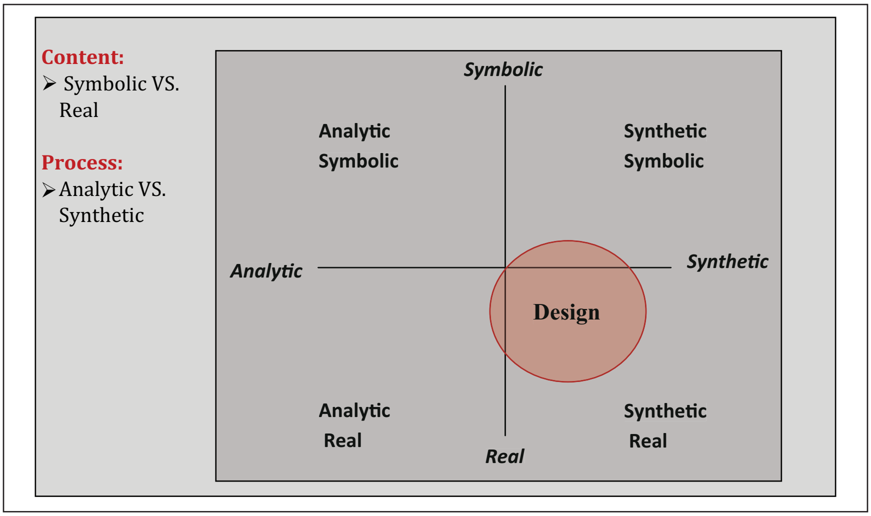

FIGURE 1. *Conceptual representation of content and process factors.*
Note. Adapted from "Design Thinking: Notes on Its Nature and Use," by C. Owen, 2007. *Design Research Quarterly, 2*(1), 16–27.

In this mapping (represented by a circle), design falls in the fourth quadrant because it is highly synthetic and strongly concerned with real-world subject matter. However, because disciplines of design deal with communications and symbolism, design has a symbolic component, and because design requires analysis to perform synthesis, there is also an analytic component (Owen, 2007).

It is important to note that a case can be made for the positioning of any field to the left or the right of the map. However, mapping fields is relative and not absolute, which is important because this mapping provides a means for comparing the relationships among different fields with respect to the two dimensions: content and process. Each of the four quadrants in this figure is important in education because we want our students to develop higher-order thinking skills and be able to analyze, synthesize, innovate, and thus readily deal with real-world problems.

According to Hatchuel and Weil (2009), design can be modeled as a relationship between two interdependent spaces with different structures and logic: the space of concepts (C) and the space of knowledge (K). Space K contains all established knowledge available for designers, while Space C includes concepts that are neither true nor false in K about an object. Design proceeds in a step-by-step partitioning of C-sets until a partitioned C-set becomes a K-set, that is, a set of objects, well defined by a true proposition in K. Thus, for Hatchuel and Weil, design is a reasoning activity that starts with a concept about a partially unknown object and attempts to expand it into other concepts and/or new knowledge.

At its core, design thinking refers to how designers *see* and how they consequently *think* (Liu, 1996). It is an iterative and interactive process where designers (a) see what is there in some representation of problem-solving concepts/ideas, (b) draw relations between ideas to solve the problem, and (c) view what has been drawn as informing further design efforts (Do & Gross, 2001; Lloyd & Scott, 1995). Designing often begins with a diagrammatic depiction that is gradually transformed to more complex graphic representations by adding detail. These design diagrams facilitate the designer's reflection, dialogue, and self-critique and therefore serve the purpose of representing and testing the designer intent. In other words, diagrams serve as a primary vehicle for thinking and solving problems (Do & Gross, 2001; Nagai & Noguchi, 2003).

Braha and Reich (2003) viewed the design process as a generic process where designers modify either the tentative or current design or the requirements and specifications, based on new information that has become available. This ongoing process of modification is performed in order to remove discrepancies and establish a fit between the problem space, expressed through requirements and specifications, and the proposed design solution.

In 2000, Suwa, Gero, and Purcell argued that designing is a situated act, which means that designers invent design issues or requirements in a way that is situated in the environment in which they design. The authors found a strong bidirectional correlation between unexpected discoveries and the invention of issues and requirements. Unexpected discoveries are those instances when a designer perceives something new in a previously drawn element of a solution concept. Not only do unexpected discoveries become the driving force for the invention of issues or requirements, but also the occurrence of invention tends to cause new unexpected discoveries. These results emphasize the importance of rapid alternation between different modes of activity during the design process (e.g., drawing sketches and conceiving of design issues or requirements that are dynamically related to one another). This also explains the opportunistic nature of design activity, as the designer pursues issues and requirements in an evolving solution concept.

According to Dorner (1999), several forms of thinking can be observed in designing. Design starts as a cloudy idea about how the design/product should look like and how it should work. With time, this idea crystallizes and transforms into a clear and complete image of the product. The cloudy idea comes from something that the designer already knows about the product. This knowledge can be a source of analogies. The second form of thinking involves the sketches and models that bring the cloudy idea to a more concrete form. Sketches and models clarify the characteristics of the product, helping to form a specific line of thought that facilitates the development process and forms the basis for the design thinking process. The third form of design thinking is the "picture-word cycle," which involves putting ideas into words that helps the designer clarify and elaborate on ideas. However, whatever the form of thinking, the design thinker should demonstrate specific characteristics in addition to creativity.

Characteristics of a Design Thinker

Table 2 summarizes some of the design thinker characteristics that Owen (2007) described. Although the nature of design thinking and what makes one person a design thinker and another not remain elusive, a number of characteristics have been identified and can be useful in understanding how a design thinker thinks and approaches issues. These characteristics are also helpful in understanding the nature of design thinking. In addition to these characteristics that a design thinker should possess, there are several processes underlying the design thinking process.

TABLE 2
Design-thinker characteristics

Characteristics	Description
Human- and environment-centered concern	Designers must continually consider how what is being created will respond to human needs. They should also consider environmental interests at a level with human interests as primary constraints for the design process.
Ability to visualize	Designers work visually (i.e., depiction of ideas).
Predisposition toward multifunctionality	Designers should look at different/multiple solutions to a problem and keep the big picture of the problem in mind while focusing on its specifics.
Systemic vision	Designers should treat problems as system problems with opportunities for systemic solutions involving different procedures and concepts to create a holistic solution.
Ability to use language as a tool	Designers should be able to verbally explain their creative process forcing invention where detail is lacking and expressing relationships not obvious visually (i.e., explanation should go hand in hand with the creative process).
Affinity for teamwork	Designers need to develop interpersonal skills that allow them to communicate across disciplines and work with other people.
Avoiding the necessity of choice	Designers search competing alternatives before moving to choice making or decision making. They try to find ways to come up with new configurations. This process leads to a solution that avoids decision and combines best possible choices.

Processes in Design Thinking

According to Braha and Reich (2003), the design process is characterized by being iterative, exploratory, and sometimes a chaotic process. It starts from some abstract specifications, or what Hatchuel and Weil (2009, p. 182) call a "brief," and terminates with the description of a product while gradually refining the product specifications. Intermediate states of the design process might include conflicting specifications and product descriptions. Specifications may change in reaction to proposals or to unexpected problems discovered during the process. In this case, design follows cycles of mutual adjustment between specifications and solutions until a final solution is reached (Hatchuel & Weil, 2009).

During the design process, designers engage in several different cognitive processes. Kolodner and Wills (1996) specified three processes required in design thinking: (a) preparation, (b) assimilation, and (c) strategic control. In the preparation process, designers need to learn what to focus on and what is relevant. During this phase, the specifications and constraints of the problem, reinterpretation of ideas, visualization, problem reformulation (including situation assessment and elaboration), and others evolve. The assimilation process involves making sense of the proposed solution, data, and observations coming from the design environment, such as feedback from experiments with prototypes. In the strategic control process, designers must make many decisions over the course of a design (e.g., which idea to elaborate or adapt next, which constraints to relax, how to set priorities). They also move among various tasks, subproblems, and design processes in a flexible and highly opportunistic manner.

In 2002, Stempfle and Badke-Schaube examined a theory of what design teams actually do while designing. They looked at theories of creativity and problem solving and cognitive theories of human decision making. The basic elements of design thinking that the authors proposed as cognitive operations to deal with any kind of problem were generation, exploration, comparison, and selection. The first two elements (generation and exploration) widen a problem space whereas the last two (comparison and selection) narrow a problem space. When widening a problem, solutions are generated and then examined in relation to the goal. Then, in an iterative process, solutions may be modified or new solutions may be developed until an optimal solution is found. Narrowing a problem entails comparing two or more ideas and then selecting the solutions based on specific and relevant goal criteria. These elements represent a model that can be applied to understand designers' thinking while working in a team. Designers working in groups have to communicate what they are thinking, thus showing their basic thinking processes.

The researchers applied this model to three mechanical engineering teams consisting of four to six students. The teams were assigned to design a mechanical concept for an optical device to project images of celestial objects. The teams interacted with a simulated customer at three fixed points in time during their one-day working period. Team communication was recorded. Results from protocol analysis revealed that the teams spent only 10% of their time on clarifying the goal and spent the remaining 90% of the time planning a solution.

The Stempfle and Badke-Schaube (2002) findings described differ from those observed by McNeill, Gero, and Warren (1998) in electronics engineers. McNeill and colleagues reported that across the whole design episode, the designers spent most of their time analyzing the problem; synthesizing the solution took the second greatest amount of time, and the remaining time was spent on the evaluation of the solution. The authors concluded that a designer begins a conceptual design session by analyzing the functional aspects of the problem. As the session progresses, the designer focuses on the three aspects—function, behavior, and structure—and then engages in a cycle of analysis, synthesis, and evaluation. Toward the end of the design session, the designer's activity is focused on synthesizing structure and evaluating the structure's behavior. Similarly, in a team of three industrial designers, Goldschmidt and Weil (1998) found that the process of design thinking is nonlinear and that designers follow a forward (breaking down) and backward (validating) reasoning strategy. Although research is not consistent about how time is spent during the design thinking process, findings indicate that there is a learning progression during the design thinking process that eventually transforms a novice into an expert design thinker.

Expertise

Expertise is the result of a dedicated application to a specific field of interest (Cross, 2004). According to Ericsson, Krampe, and Tesch-Romer (1993), deliberate practice guided toward improvement of performance is necessary to reach high levels of performance and the acquisition of expertise. Ericsson et al. added that the achieved level of performance of an expert is closely related to the accumulated amount of practice. Therefore, the development of expertise passes through different phases. Something happens in the development from being a novice to becoming an expert.

The major difference between experts and novices is that experts have accumulated a large number of examples of problems and solutions in a specific domain of interest. A key competency of an expert is the ability to mentally stand back from the specifics of the accumulated examples and form more abstract conceptualizations related to their domain of expertise (Akin & Akin, 1996; Ho, 2001). Experts are believed to be able to store and access information in larger cognitive chunks than novices can and to recognize underlying principles rather than focusing on the surface features of problems (Dorner, 1999; Nigel, 2004; Purcell & Gero, 1996; Suwa et al., 2000). Therefore, the accumulation of experience is critical in the transformation from a novice to an expert.

In many areas, like sports and music, the benefits of dedicated practice are well known and there are established programs of training for novices to help them gain experience and expertise over time (Cross, 2004). It may be beneficial in other areas as well to focus on the transformational phases (i.e., novice through expert), such as in design thinking. In design education, there are well-established practices that are presumed to help the development from novice to expert, but there is still little understanding of the differences between novice and expert performance in design.

Novice Versus Expert Design Thinker

In general, a good designer should be able to flexibly use different problem-solving strategies and choose the one that best meets the requirements of the situation (Akin & Akin, 1996; Eisentraut, 1999; Weth, 1999). Regardless of the given problem, successful designers clarify requirements, actively search for information (i.e., critically check given requirements and question their own requirements), summarize information of the problem into requirements and partially prioritize them, and do not suppress first solution ideas (Badke-Schaub, 1999; Fricke, 1999).

According to Nigel (2004), novice behavior is usually associated with a depth-first approach to problem solving, that is, identifying and exploring sub-solutions in depth and sequentially. The strategies of experts are usually regarded as being predominantly top-down, breadth-first approaches. The expert designer uses explicit problem decomposing strategies, which the novice designer does not possess. In 2001, Ho examined the search strategies used by expert and novice designers in solving problems in industrial design. Using protocol analysis, the researcher found that the novice participant focused only on the surface level without decomposing the problem, while the expert used explicit problem decomposing strategies. However, both expert and novice used similar bottom-up (working-backward) problem-solving strategies.

Christiaans and Dorst (1992) conducted protocol studies of junior and senior college students in an industrial design course. They found that some students, mostly the juniors, got trapped gathering information rather than progressing to solution generation, but most of the senior students did not face this difficulty. That is, senior design students did not gather as much information, but they were able to solve the given problem. They asked for less information, processed it directly, and built up an image of the problem. They also prioritized activities early in the process.

A similar finding was reported by Gunther and Ehrlenspiel (1999), who conducted a set of experiments with a total of 20 novice and expert designers of mechanical devices. The researchers found that experts were able to clarify a task in a shorter time, whereas novices had to invest much more time in clarification. These findings (i.e., Christiaans & Dorst, 1992; Gunther & Ehrlenspiel, 1999) corroborate findings from Atman, Chimka, Bursic, and Nachtman (1999), who conducted protocol analysis studies of engineering students. They found that novices (i.e., freshmen with no design experience) spent a large portion of their time defining the problem and did not produce high-quality designs. Therefore, and similar to the industrial design students in the Christiaans and Dorst (1992) study, some of the freshmen engineering students in the Atman et al. study were stuck at the level of defining the problem, which hindered their progress in the design process. However, senior students defined the problem adequately, which in turn resulted in good designs.

Ahmed, Wallace, and Blessing (2003) studied differences between the behaviors of novice and experienced designers in engineering. The authors found clear differences between the behavior of new graduate entrants (i.e., novices) to the engineering design profession and experienced designers. The novices used trial-and-error techniques of generating and implementing a design modification, evaluating it, and then generating another evaluation through several iterations. Experienced engineers, however, made a preliminary evaluation of their tentative design decisions before implementing them and making a final evaluation. In contrast to the novices' trial-and-error approach, the experienced designers employed integrated design strategies.

In 2001, Seitamaa-Hakkarainen and Hakkarainen investigated the relationships between visual and technical designing using qualitative analysis. That is, they examined differences between two novices and two experts in the field of weaving design. Protocol analysis results revealed that the experts integrated the visual elements (e.g., color, size, patterns) and technical elements (e.g., material) of weaving, and generally considered them in a parallel way during the design process. Iteration between the visual and the technical space was a significant aspect of the experts' design process. The experts continuously moved from one design space to another to carry out very detailed processes of search for design solutions. In contrast, the novices organized their process around the composition space and rarely moved to the construction space to explore how visual ideas could be realized in weaving.

Similarly, using data from protocol studies, Kavakli and Gero (2002) compared the cognitive performances/actions (i.e., looking, perceptual and functional actions, and goals) of a novice and an expert architect. Using protocol analysis, the researchers investigated concurrent cognitive actions of designers and found significant differences in output between novice and expert designers. The protocol was divided into segments. A cognitive segment consisted of cognitive actions that appeared to occur simultaneously. They found that the design protocol of the expert included 2,916 actions (i.e., chunks) and 348 segments, whereas the novice's protocol included 1,027 actions and 122 segments. Each segment consisted of 8 cognitive actions on average. Considering that the same amount of time was given to both participants, the expert's design protocol was 2.8 times as rich as the novice's in terms of actions. There were also 2.8 times as many segments in the expert designer's session as in the novice's. Therefore, the expert had more overall fluency in relation to divergent thinking skills. The expert's cognitive actions continuously rose throughout the activity, while the novice's cognitive activity started at a peak and then declined. The authors also found that the expert seemed to have more control of his cognitive activity compared to the novice. Because the expert's cognitive actions are well organized, he was able to govern his performance more efficiently than the novice.

These findings align with those by Tang and Gero (2001), who found substantial differences between a novice and an expert architect. Using a retrospective protocol analysis, the authors found differences between the novice and expert designers in relation to four design levels: (a) the *physical* level, which refers to the instances that have direct relevance to the external world, comprising drawing and looking actions; (b) the *perceptual* level, which concerns the instances of attending to visual-spatial features/relationships in an automatic perceptual mechanism; (c) the *functional* level, which relates to the instances of functional references mapped between visual-spatial features/relationships and abstract concepts, including meanings and functions; and (d) the *conceptual* level, which represents the instances that process abstract concepts and the instances that process physical and perceptual actions. The expert seemed to create more meaning at the physical and perceptual levels than the novice.

Differences between novices and experts performing design-related problems were also studied by Göker (1997). The author examined novices and experts on a task involving computer-simulated construction of machines. Göker found that the experts, skilled in the use of computer simulations, did not reason toward a design concept in an abstract way, but relied more on their experience and visual information. In contrast, novices depended more on abstract reasoning.

Experts During the Design Process

Expert designers solve complex problems more easily than novices (Cross, 2004). During a conceptual design process, experienced designers do not just synthesize solutions that satisfy given requirements, they also invent design issues or requirements that capture important aspects of a given problem that assist in solving the problem at hand (Liu, 1996). From protocol studies of experienced engineering designers, Lloyd and Scott (1994) found that the manner by which experts approach a problem is related to the degree and type of previous experience. More experienced designers tend to use generative reasoning (i.e., an inductive approach) compared to less experienced designers who employ more deductive reasoning (depth-first approach). In other words, designers with specific experiences related to the problem type approached the design task through solution assumptions/conjectures instead of problem analysis. This hypothesis suggests that experience in a specific problem type enables designers to perceive the design problem in terms of relevant solutions that they have previously encountered.

Designers also tend to change goals and constraints as they design. They are flexible in selecting and trying different solutions. However, when designers face unexpected difficulties and/or shortcomings in the solution concept, they tend to stick to their principal solution concept as long as possible through the design process. For instance, from case studies of professional architectural designers, Rowe (1987) observed that the designers' choices for problem-solving directions were influenced by their initial design ideas. Furthermore, the designers made every effort to make these ideas work whenever a problem was encountered, rather than adopting a new idea.

And although this fixedness proclivity may sound maladaptive, Ullman, Dietterich, and Stauffer (1988) observed the same phenomenon in their protocol studies of experienced mechanical engineering designers. Ullman and colleagues found that experienced designers typically pursued only one design proposal. And even when major problems had been identified, the designers preferred to modify the initial proposal rather than rejecting it and developing a new one. Likewise, Ball, Evans, and Dennis (1994) drew a similar conclusion from their studies of senior electronic engineers conducting real-world projects. The researchers stated that when the designers generated a less than satisfactory solution, they refused to discard the original solution or spend time and effort coming up with an alternative one. Rather, they tended to improve the solution by developing different versions until a workable solution was achieved. Again, the designers indicated a fixation behavior on initial concepts (Ball et al., 1994). Nonetheless, adherence to initial concepts seems to comprise normal expert design behavior. Finally, in a study of experienced software designers, Guindon (1990) also found that designers came to a solution very early in the session and quickly rejected alternative solutions.

Since a problem cannot be fully understood in isolation, expert designers use conjectures as a means of helping them to explore and understand the formulation of the problem. From protocol studies of experienced industrial designers, Dorst and Cross (2001) asserted that the designers start by exploring the problem and find, discover, or recognize a partial structure. Afterwards, they use this partial structure to generate initial ideas for the form of a design concept, then expand and develop the partial structure. Thus, their goal is to create a matching solution to the problem. Having more than one solution concept should stimulate a more comprehensive evaluation and understanding of the problem (Cross, 2004). From the analysis and synthesis of the literature, it appears that there are a number of competencies that designers should acquire and hone. The more experience a designer builds in these competencies, the more he or she advances along the novice-expert continuum.

Design Thinking Competency Model

As a result of this review of the literature, we have created a design thinking competency model (Figure 2), adapted from Shute and Torres (2012). This model displays a hierarchically arrayed set of variables (or nodes), from general to more specific when viewing from left to right. This competency model represents an

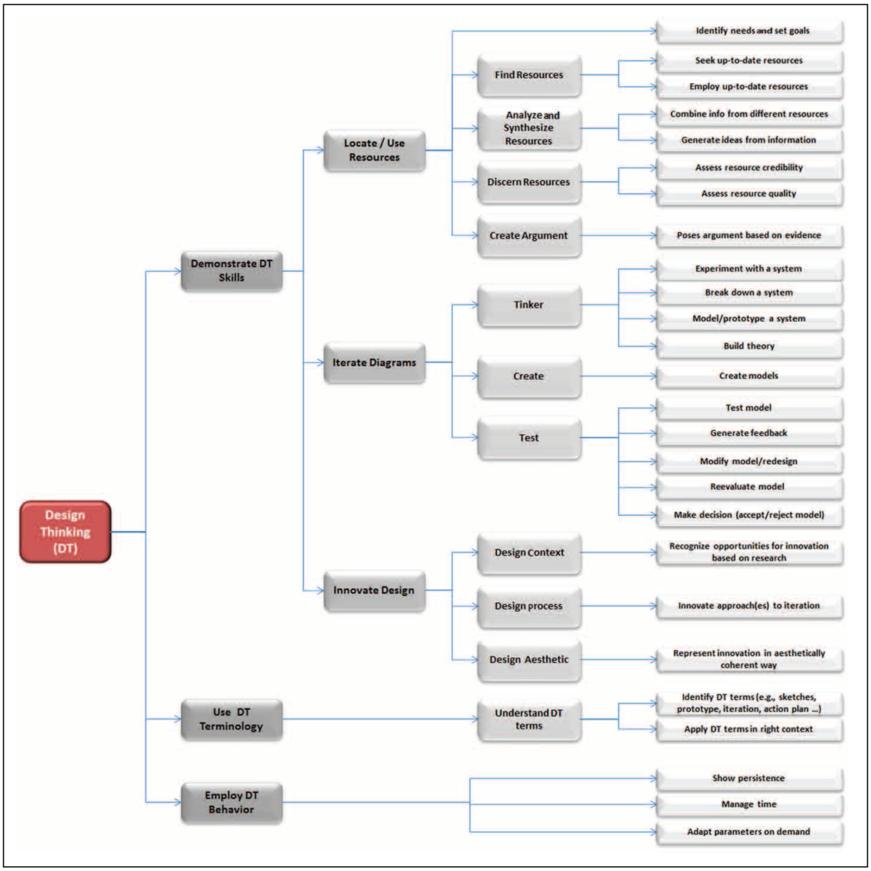

FIGURE 2. *The design thinking competency model.*
Note. Adapted from "Where Streams Converge: Using Evidence-Centered Design to Assess Quest to Learn." In M. Mayrath, J. Clarke-Midura, & D.H. Robinson (Eds.), Technology-Based Assessments for 21st Century-Skills: Theoretical and Practical Implications from Modern Research (pp. 91-124). Charlotte, NC: Information Age Publishing.

operationalization of the design thinking construct and may also help drive the creation of appropriate activities that would allow for the collection of relevant evidence to inform variables in the model. For example, consider the variable "Iterate Diagrams" in Figure 2. Skills associated with this variable include tinkering, creating, and testing ideas via diagrams. Testing, in turn, entails initial testing of the design idea, getting feedback, modifying the design, reevaluating it, and making a decision to accept or reject the modeled idea. To assess students' competency levels relative to the iterate diagrams variable, we would have to put them in a situation in which those constituent skills could be employed, such as in a game or simulation. Diagnostically, the model could provide the framework for evaluating the degree to which students are demonstrating particular design thinking skills at various times and at various grain sizes relative to the model (for more, see Shute & Torres, 2012).

The design thinking competency model is useful for assessment and diagnostic purposes. That is, once the key knowledge and skills have been identified, then tasks and activities can be developed in line with the model's variables. Another relevant question concerns whether these skills are learnable. With sufficient practice within meaningful environments, along with scaffolded support and formative feedback, we believe that students can learn design thinking skills. Moreover, pedagogical approaches that involve problem-based learning, project-based learning, and inquiry-based learning can be used to enhance students' design thinking skills within the context of evocative and consequential classroom activities (Dym et al., 2005).

Such learner-centered approaches can help to raise students' awareness about good design processes and generally enhance their interest in solving complex problems. Associated activities could be designed in a way that requires students to generate ideas/solutions, receive support for their emergent design thinking skills, as well as ongoing feedback about the feasibility of various solutions. Educators can support their students in developing these skills by providing them with multiple and varied opportunities to design and create prototypes, experiment with different ideas, collaborate with others, reflect on their learning, and repeat the cycle while revising and improving each time.

In summary, the premise is that by improving students' design thinking skills through having them apply processes and methods that designers use to ideate and help them experience how designers approach problems to try to solve them, students will be more ready to face problems, think outside of the box, and come up with innovative solutions. We believe that design thinking is more than just a skill to be acquired and used in limited contexts. Rather, we view it as a way of thinking and being that can potentially enhance the epistemological and ontological nature of schooling.

Summary and Discussion

In this article, we reviewed the literature related to design thinking. Expert designers are solution focused rather than problem focused. This appears to be a feature of design thinking that comes with education and experience in designing (Cross, 2004). Specifically, building experience in a particular domain allows designers to quickly identify the problem and propose a solution. Generating, synthesizing, and evaluating a solution are frequently identified as key features of design expertise. Some research studies (e.g., Dorst & Cross, 2001; Guindon, 1990) have found that creative and productive design behavior seems to be associated with frequent switching of types of cognitive activity (e.g., analysis, synthesis). Designers should be able to assess the conditions of a given situation and quickly adjust their actions depending on the current set of needs (Stempfle & Badke-Schaube, 2002).

Helping students to think like designers may better prepare them to deal with difficult situations and to solve complex problems in school, in their careers, and in life in general. Current educational practices, though, typically adhere to outdated theories of learning and pedagogy, evidenced by a so-called content fetish (Gee, 2005). That is, schools continue to focus on increasing students' proficiency in traditional subjects such as math and reading, via didactic approaches, which leaves many students disengaged. We can and should move beyond that limited focus and consider new educationally valuable skills (e.g., design thinking, multitasking, digital literacy) to value, assess, and support.

As described earlier, enhancing students' design thinking skills may be achieved through incorporating authentic and intriguing tasks into the classroom and providing many opportunities to apply design processes. In our design thinking model shown in Figure 2, imagine tasks that are designed and developed for each of the low-level nodes. As students work on the tasks, evidence is accumulated to evaluate their performance. Such information can help educators monitor the student's performance, infer current states of strength and weakness relative to design thinking variables, and provide targeted feedback to improve the student's performance. Our goal as educators should not focus on preparing our students to perform well on standardized exams, but to equip them with powerful skill sets that can help them succeed both within and outside of school.

This article presented relevant research that has provided the basis for understanding (a) the nature of design thinking, (b) experts' behavior in design, and (c) differences between novice and expert designers. Most of these studies were qualitative and employed protocol analysis, which has some limitations as a research method, especially for investigating design activities. For example, it can be a weak method when researchers aim to capture designers' nonverbal thought processes, which are critical in design thinking. The majority of the studies we reviewed aimed to examine either the differences between novice and expert designers or characterize expert behavior in the designing process. However, experimental evidence is lacking in the field of design research.

Researchers who are interested in measuring and supporting design thinking have great opportunities to conduct a wide range of experimental studies that can lead to important findings. For instance, researchers may examine the effects of the design thinking process on various learning outcomes. They can also investigate the effects of different tasks and their complexity relative to enhancing design thinking skills, which in turn are assumed to increase students' learning outcomes. It would also be interesting to know if design thinking skills mediate the learning process. In other words, design thinking skill may serve as a mediator that clarifies the nature of the relationship between an independent variable (e.g., problem-solving skill) and a dependent variable (e.g., math test scores). So, rather than hypothesizing a direct causal relationship between problem-solving skill and math test scores, we may hypothesize that problem-solving skill enhances design thinking skill, which in turn leads to an increase in math scores. Another important study could examine the domain-specific versus domain-independent nature of design thinking. In other words, can design thinking skill be examined independently of particular domains (e.g., engineering vs. marketing), or is it context bound?

Currently, we have found no valid performance-based assessments of design thinking skills. This lack adversely affects the ability to collect good evidence about the effects of these skills on learning (Rotherham & Willingham, 2009). A major challenge, then, is to design and develop accurate, performance-based measures of these skills. Assessing these types of 21st-century competencies is beyond the capabilities of most traditional assessment formats (e.g., multiple-choice test, self-report survey). Therefore, innovative assessments that aim to reliably measure those skills should be designed and developed to assist researchers in collecting valid and reliable evidence. We suggest employing the evidence centered design

(ECD) framework (Mislevy, Steinberg, & Almond, 2003) for designing valid performance-based assessments for 21st-century skills. ECD is a systematic approach to the design of assessments that focuses on the evidence (i.e., student performance and products) of proficiencies as the basis for constructing assessment tasks and making inferences about competency levels (for more, see Mislevy et al., 2003). ECD is especially suited for assessments that involve complex problems and dynamic, interactive environments—which are exactly the kinds of contexts required for design problems.

There is considerable empirical work to be done to establish a full understanding of design thinking. The studies surveyed in this article show the characteristics of novice and expert designers. Having good design thinking skills can assist in solving really complex problems as well as adjusting to unexpected changes. Although the design process involves in-depth cognitive processes—which may help our students build their critical thinking skills (e.g., reasoning and analysis)—it also involves personality and dispositional traits such as persistence and creativity. If we are serious about preparing students to succeed in the world, we should not require that they memorize facts and repeat them on demand; rather, we should provide them with opportunities to interact with content, think critically about it, and use it to create new information. Preparation for future work situations requires teaching learners to use their minds well. To turn the tide in education that is leaving students "ill-prepared to tackle real-world, complex problems [we must change our course] . . . we cannot directly adjust the wind (the future), but we can adjust

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