What is the Content of "Design Thinking"? Design Heuristics as *Conceptual Repertoire*

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Abstract

When engaged in design activity, what does a designer think about? And how does she draw on disciplinary knowledge, precedent, and other strategies in her design process in order to imagine new possible futures? In this paper, we explore Design Heuristics as a form of intermediate-level knowledge that may explain how designers build on existing knowledge of "design moves"—non-deterministic, generative strategies or heuristics—during conceptual design activity. We describe a set of relationships between disciplinary training and the acquisition of such heuristics, and postulate how design students might accelerate their development of expertise. We conclude with implications for future research on the development of expertise, and the ways in which methods such as Design Heuristics can enhance this developmental process.

Keywords

Design Heuristics; design thinking; conceptual repertoire; design precedent; intermediate-level knowledge; design cognition; design pedagogy

I. Introduction

When engaged in design thinking, what is a designer thinking about? The importance of the design process as key to innovation is well established [30,37], but to get to great solutions, we know that designers must "scope, generate, evaluate, and realize ideas"

[36]. This process of realizing ideas through a range of design activities is not well understood, particularly in relation to how these abilities can be taught or developed over time [6,14]. When engaging in design activity in an educational environment, students learn to tackle design within collaborative teams by exploring a problem space with hands-on research *(what is)*, exploring a related solution space with various ideation techniques *(what if)*, and aligning the ideas with reality through repeated feedback and iteration to revise the selected paths towards a solution *(what becomes)* [26]. We focus primarily on the ideation stage in this paper, discussing how designers explore a solution space through the generation of potential solutions, and address the nature of design cognition, or "designerly ways of knowing" [6], that makes idea exploration possible.

Design scholars have built descriptive design theory that can explain aspects of the idea generation process, often pictured as a dialectic between problem and solution [4,13], where a movement between convergence and divergence [2,14], incorporation of user research to encourage the inclusion of human-centered design principles [19], framing and traversal of the problem space [12], and precedent knowledge [24,32,31] all fuel the generation of ideas. In this paper, we provide one account for an idea generation process in relation to designers' knowledge of existing design artifacts and design strategies (e.g., patterns, best practices, heuristics).

When engaged in design activity, a designer often chooses to add variation to conceptual designs in order to address the problem in a novel way. *Design Heuristics* capture the ways that designers modify product concepts, and are based on observed patterns of conceptual development in empirical studies of past product designs [40,41]. For example, one design strategy is to "make use of all surfaces available" when generating a design; a shelf is designed to hold objects, but also provides an underside that can serve other purposes. This strategy is captured in a *Design Heuristic*, "Use opposite surface," displayed on two sides of a card (Figure 1). In this way, knowledge extracted from past designs can be constructively and generatively applied to create new designs as demonstrated by the product examples shown on the reverse of each card. Seventy-seven separate *Design Heuristics* have been empirically identified [11], each capturing design strategies shown to be salient in past design concepts—both in iterative design activity and final products. For example, one student given the "Utilize Opposite Surface" heuristic card created a concept where the inner part of the case is used to hold water in tubes and get it warmed up using the photo cells to heat the cooking surface on the go (Figure 2).

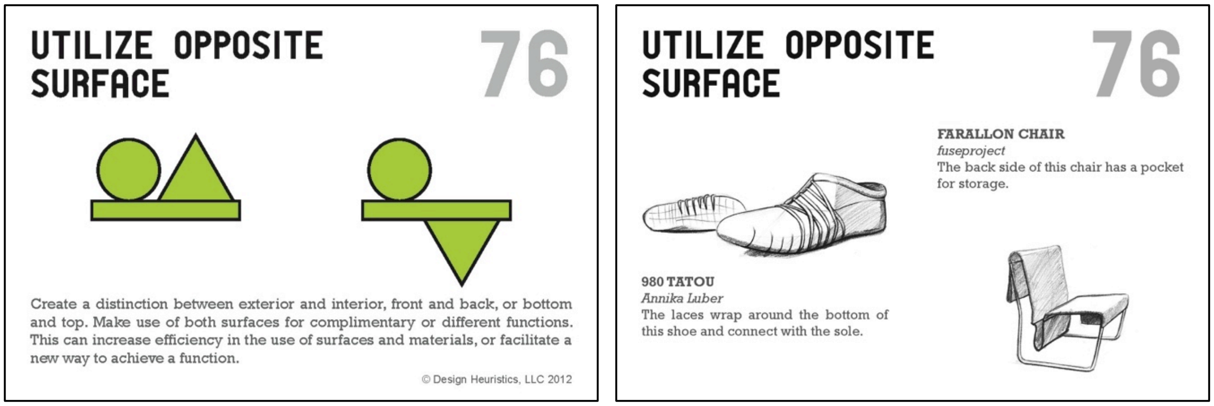

Figure 1: The Design Heuristic, “Utilize opposite surface,” provides a text and a graphical description on one side of a card, and two examples of products illustrating it on the other.

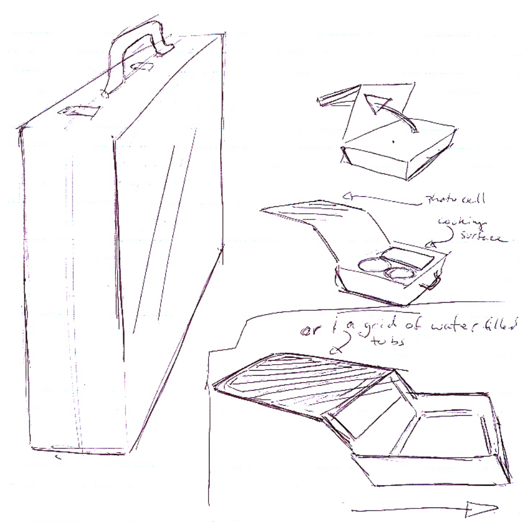

Figure 2. An example of a student work using the “Utilize opposite surface” as a heuristic.

Synthesis of existing work on Design Heuristics

Some available idea generation methods describe the knowledge abstracted from an artifact as abstract principles (e.g., Synectics, SCAMPER), while others recommend principles based on how tradeoffs have been addressed in prior in design patents (TRIZ, SIT). *Design Heuristics* capture patterns of how to generate successful designs on an intermediate and strategic level, linking the designer to past successful solutions without explicitly prescribing what to do or how to do it. Design Heuristics lie within a region of knowledge that Höök and Löwgren identify as “more abstracted than particular instances, yet does not aspire to the generality of a theory” [21]. In addition, unlike other existing idea generation methods, *Design Heuristics* are empirically grounded in precedent artifacts and designs and are empirically validated [39].

The goal of this paper is to link previous findings that document the effectiveness of Design Heuristics [9-11,40-42] to a cognitive account of how conceptual knowledge and expertise is constructed over time. Design Heuristics have been found to foster the development of design expertise; but how does this development occur, and how does it reflect a developing designer's lived experience and understanding of disciplinary precedent? In this paper, we describe several relationships between design precedent and heuristic knowledge, and then relate this intermediate-level knowledge to the use of Design Heuristics in engineering education.

II. Design Precedent and Intermediate-Level Knowledge

Design research indicates that successful ideation involves exploring the problem and solution space simultaneously [13,28], as well as engaging in both divergent and convergent thinking. Throughout design processes, designers ask questions, narrow down the selection of their problem criteria, generate multiple ideas for consideration, and develop and elaborate on existing ideas [4,15,18]. As in many areas of expertise, design thinking often involves analogy to past solutions, or precedents that can be usefully applied in future work [5,20,22,25].

While knowledge of precedent artifacts is relatively straightforward—as documentation of what has been created—the generation of an intermediate form of knowledge that represents the curatorial dimension above the precedent or ultimate particular level is substantially more complex and abstract. Scholars within the design community have noted that this intermediate-level form of knowledge is underdeveloped in many disciplines, as it fits neither the category of precedent artifact nor scientific theory [e.g., 29]. Two recent attempts to further develop this intermediate space are *bridging concepts* between empirically grounded theory and practical use [7], and *strong concepts,* a form of intermediate-level knowledge describing core design ideas that are inherently generative [21]. Another concept, *collections* or *annotated portfolios* [e.g., 27], reflects practices that already commonly occur in the research phase of a design process (e.g., comparative market analysis). This form of intermediate-level knowledge generation affords the generation of conceptual structures that are abstracted beyond a particular design artifact, and thus represent an approach, strategy, or generative hint towards a class of design moves, rather than a prescriptive or otherwise deterministic connection [17].

Beyond a collection of distinct designed artifacts, past research has analyzed the characteristics that bind certain design approaches together, as in Alexander's *pattern language* [1], Krippendorf's *design discourses* [23], conceptual primitives [33], or language of thought [16]. These approaches provide insight into how disciplinary knowledge might be distilled into intermediate-level knowledge, built by constructing composite pieces that originate in situated knowledge [38]. Following this concept of *pattern language*, we posit that the content of design thinking—as a distinct human activity and epistemology [3,29]—can be identified from its appearance in situated design activity.

Through close analysis of concepts created by designers, patterns of intermediate-level knowledge can be discerned, which we characterize as *Design Heuristics*.

III. *Design Heuristics* as Conceptual Repertoire

Schön [34] characterized the design process as a reflective "conversation" between the designer and the artifact being designed. Within this conversation, the designer mediates between the design project at hand, a lifetime of lived experiences, knowledge of existing solutions (i.e., precedents), and cognitive schema that relate these elements to each other [8]. Schön [35] refers to this store of precedents as a designer's *repertoire*, or a personal source of generative metaphors. More broadly, repertoire can be found in curated or canonical forms in collections of precedents (e.g., the "best designs of the year" lists), often created by experts within a given design discipline. Beyond this knowledge of the particular, an experienced designer also carries with them a *conceptual* repertoire—similar to a curated collection, yet largely buried in memory as tacit knowledge—which they are able to apply to new design problems. We propose that the use of *Design Heuristics* builds an individual designer's repertoire [35] of conceptual content capturing the ontology of design strategies facilitating idea generation. This *conceptual repertoire* represents a collection of intermediate-level knowledge that is built on experiential precedents, containing successful patterns of design reasoning that, in their formation and use, assist the designer in creating new design concepts.

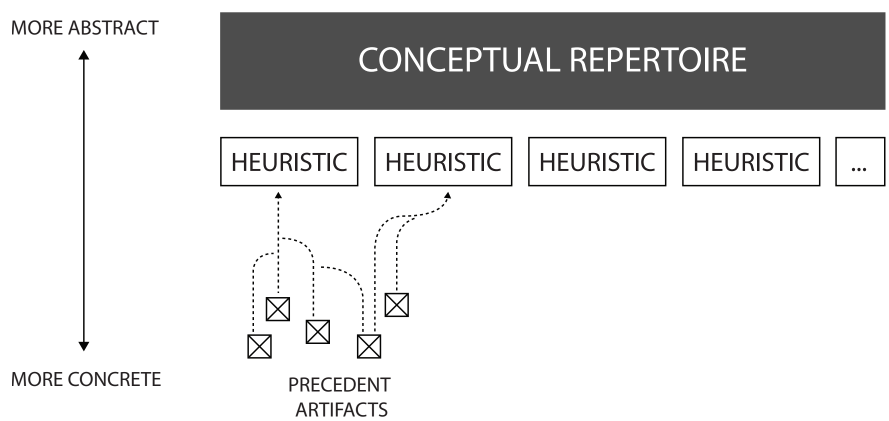

Figure 3: Levels of abstraction as design knowledge is acquired, and precedent artifacts are reified into intermediate-level forms of knowledge.

A conceptual repertoire shares many similarities to Alexander's pattern language, in that patterns have classificatory or curatorial qualities that transcend individual precedents (Figure 3). In *Design Heuristics*, we are not only identifying potential patterns (thus building intermediate-level knowledge) from discrete precedent artifacts, but are also able to use these patterns to tie individual design concepts to a larger disciplinary canon of strategies. In Alexander's pattern language, recurring design problems are linked with canonical solutions non-deterministically; that is, as a "likely" solution given historical precedence. *Design Heuristics* make the same claim: intermediate distillations of content knowledge about designs, in particular the cataloguing of design strategies, can suggest possible solutions for the designer to explore in a non-deterministic manner [40].

In empirical studies, the use of *Design Heuristics* has been shown to scaffold the metacognitive development of early engineering students [9], and to facilitate the generation of novel concepts even in experienced designers [42]. Even beginning designers can examine a heuristic card, and successfully use the intermediate-level knowledge it contains to extend or redefine a design concept [9-11]. This demonstrates their potential for linking design concepts and knowledge about idea generation in a fluid, bidirectional manner. We propose that a designer builds dynamic links between disciplinary canon (containing both precedents and intermediate-level knowledge of strategies) and their own conceptual repertoire (Figure 4). Over time, the heuristics become incorporated into the designer's individual repertoire.

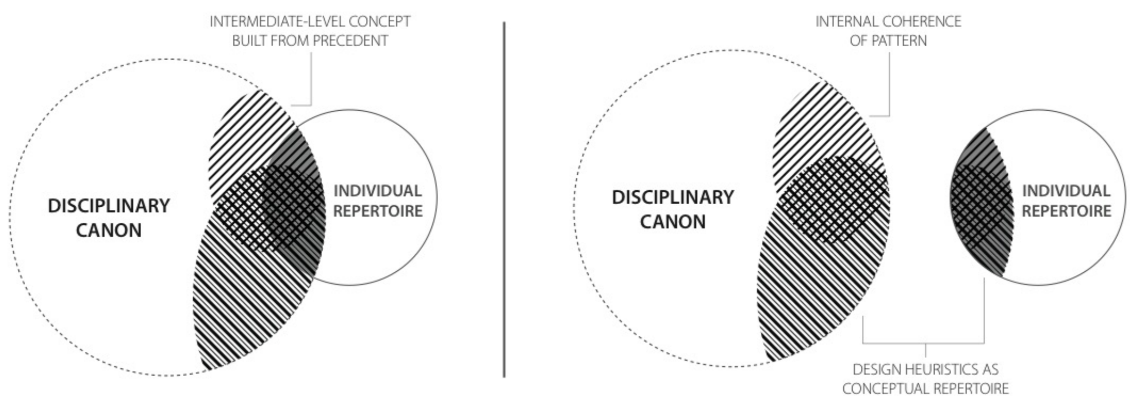

Figure 4: Relationship of the disciplinary canon and underlying conceptual repertoire to a developing designer's repertoire.

Design Heuristics translate the components or design moves used in individual concepts into an organized repertoire. Designers are then able to use this translational process to locate and document areas of internal coherence in their own practice. The power of this approach comes through the nature of the intermediate-level knowledge identified—positioned between formal theory and the ultimate particular; specifically, this form of knowledge is not prescriptive (i.e., tells the designer *what* to do), but rather heuristic (i.e., makes an inductive argument established through the usefulness of previous concepts generated). The resulting intermediate-level knowledge about successful design moves demonstrates both variety of execution and an implicit argument regarding effectiveness or efficacy. *Design Heuristics* are just one of many possible articulations of precedent curation into a conceptual repertoire, and as such comprise only one form or class of intermediate-level knowledge.

Progressing one level deeper, we can explore the affordances of the *Design Heuristics* method. Different knowledge or validity claims are made by different portions of the heuristic cards. These constitute different ontological arguments, and taken together, comprise a formalization of intermediate-level knowledge. The precedent artifacts on the reverse of the card most explicitly substantiate the curatorial aspect—supporting the heuristic through physical examples, documenting ultimate particulars that led to the creation of the heuristic, or otherwise exemplify its content. The title of the heuristic is then a reification of this curation, translating the similarities between precedent instances (beyond those on the card) into a labeled concept or phenomenon. The description and simplified graphic representation, then, is a documentation of the inductive conclusion that holds the examples together—both those present on the card, and the larger empirical work on which the heuristics are based. The designer or user of the card can then make sense of and generatively use not only the heuristic, but also trace its coherence and internal validity using the variety of evidence provided.

These heuristic cards are then used by a designer through a process of abduction, with the designer responsible for selecting a heuristic and imagining how it might be used to transform or redefine an existing concept. This is the essence of the cognitive skill that permeates design: taking a stimulus, such as a *Design Heuristic*, and using it as a gambit or abductive hypothesis [24] to imagine a design space where an alteration of a concept, or a new concept altogether, is possible. Thus, this translational and generative process implicates an element of the conceptual repertoire within the known disciplinary canon, linking the designer's present context and problem space definition to that designer's own conceptual repertoire through a potential solution or opportunity space. The generative process that leads to the creation of a potential design can then be traced, showing the implicit pedigree of precedent artifacts and related intermediate-level knowledge that led to the new concept. This documentation of pedigree may reveal the patterns of thought and linking of concepts—from new context to existing strategies from a designer's conceptual repertoire—that allowed for the creation of innovative concepts, expanding our collective understanding of the ways in which creativity impacts the ideation process.

IV. Implications for Engineering Design Education

Educational approaches to teaching design thinking in other design disciplines (e.g., architecture, industrial design) have focused primarily on the learner's exposure to precedent exemplars—or ultimate particulars [29]— to build this repertoire [24]. The traditional studio educational experience pioneered in design education centuries ago follows this pattern, with an explicit focus on learning a relatively well-defined canon of examples [e.g., 32]. While design is a core focus in engineering education, the use of exemplars is less common or not well documented [10]. We posit that exposure to *Design Heuristics* can hasten, or even enable the learner's trajectory, especially in cases where little formal canon or support for formalized repertoire currently exists. *Design Heuristics* scaffold the construction of conceptual repertoire by implicitly communicating the teleology and epistemology of design, as empirically derived from multiple examples. In this way, methods such as Design Heuristics that explicitly bridge precedent artifacts and form useful patterns of disciplinary knowledge are able to foreground intermediate-level knowledge in a way that scaffold students' understanding of design thinking.

Not all designers experience the same types of problems that lead to the creation of successful heuristics. Repertoire is related not only to disciplinary canon, but also lived experience in its many forms. Some students may be predisposed to more easily integrate some heuristics due to their prior experiences, but the relationship between experience and heuristic acquisition (i.e., adding a heuristic to one's conceptual repertoire) is not yet well understood. However, from empirical studies, we know that exposure to the Design Heuristics cards can "jump start" learning by demonstrating heuristics found to be effective by experienced designers [9-11]. While not every heuristic must be incorporated into every designer's repertoire, we would expect experts to have a substantial body of intermediate-level knowledge at their disposal, which is constantly being enriched, connected, and renewed through new experiences and precedent artifacts.

Some forms of design education are predicated on the knowledge of canon first, only allowing the implementation of variation later in the learning experience (e.g., copying successful designs before creating ones' own). We propose that introducing intermediate-level knowledge early in the learning process as externalized conceptual repertoire can scaffold the development of internal coherence. This scaffolding of students' design cognition in an educational context may progress as follows:

1. Instructors build students' knowledge of curated intermediate-level concepts (e.g., *Design Heuristics*) concomitantly with organic idea generation
2. Instructors and students relate intermediate-level concepts to the design artifacts (i.e., ultimate particulars) being generated
3. Students are then able to transfer the intermediate-level knowledge to a new concept in a different context
4. Over time, students begin to internalize the intermediate-level knowledge as a design pattern or guiding pattern of internal coherence, which functions as a cognitive schema, organizing past elements in the conceptual repertoire and preparing the repertoire for additional growth in the future (i.e., building a library of "design moves")

While reliance on existing precedent materials is not uncommon within engineering education, the explicit focus on the building of cognitive schema recontextualizes many common learning activities. Instead of content delivery or rich practice through authentic tasks, focusing on the acquisition and utilization of intermediate-level knowledge allows for an increased understanding of the intersection between personal knowledge and schema (i.e., conceptual repertoire) and the canon or conceptual boundaries of the discipline. So while the construction of conceptual knowledge (#1), and the generalization of this conceptual knowledge across multiple instances (#3) are common in engineering education, the awareness of this conceptual knowledge created through explicitly relating intermediate-level concepts to design artifacts (#2) represents a new emphasis in the instructional process. This relational process involves explicitly noting a change in a design concept, creating a language to describe the change or design move that goes beyond the particular design context. This language is constructed in the form of a broader heuristic that may prove generatively useful in other design situations. This languaging of generative strategies in a more abstract form demonstrates to beginning designers how innovations embodied within a specific design can be described and discussed as an intermediate-level of knowledge.

Heuristic generation, as we have demonstrated with *Design Heuristics* [9-11,40-42], serves both as a legitimation of precedent gathering practices—crucial for building a shared canon—and also supports the practice of inductive reasoning that occurs through the combination and classification of such artifacts. Further research is needed to document the development of conceptual repertoire, and the relationship of these cognitive structures to precedent artifacts and learning experiences. While previous studies have focused primarily on validation of Design Heuristics through experimental research, longitudinal studies within the phenomenological and interpretivist traditions will allow for a richer exploration of the development of conceptual repertoire, and the learning experiences that foster this kind of metacognitive development over time.

V. Conclusion

We propose that *Design Heuristics* offer a conceptual bridge between design theories and the individual design precedents often provided to learners, forming a body of intermediate-level knowledge that is valuable in engineering design education and practice. We posit *Design Heuristics* as a collection of strategies that connect and build upon existing precedents, demonstrating generative value in the development of design ability and in the practice of design. This focus on the *content* of design thinking—what the designer is thinking about as they consider new concepts—is an important contribution to design theory, and represents a new way of conceiving the links designers form between precedent artifacts and their own conceptual repertoire.

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VII. Authors' biographies

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Seda Yilmaz is an Associate Professor of Industrial Design at Iowa State University. She teaches project-based design studios and lecture courses on developing creativity and research skills. Her current research focuses on identifying impacts of different factors on ideation of designers and engineers, developing instructional materials for design ideation, and exploring foundations of innovation. She often conducts workshops on design thinking to a diverse range of groups including student and professional engineers and faculty members from different universities. She received her PhD degree in Design Science in 2010 from University of Michigan.

Shanna R. Daly is an Assistant Professor in Mechanical Engineering at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton (2003) and a Ph.D. in Engineering Education from Purdue University (2008). Her research focuses on strategies for design innovations through divergent and convergent thinking as well as through deep needs and community assessments using design ethnography, and translating those strategies to design tools and education. She teaches design and entrepreneurship courses at the undergraduate and graduate levels, focusing on front-end design processes.

Richard Gonzalez holds a Ph.D. from Stanford University in Psychology. He is a professor of Psychology, Statistics, and Business at the University of Michigan, and is the Director of the Center for Human Growth and Development at the Institute for Social Research. He studies design, decision making, applied statistics and mathematical modeling.