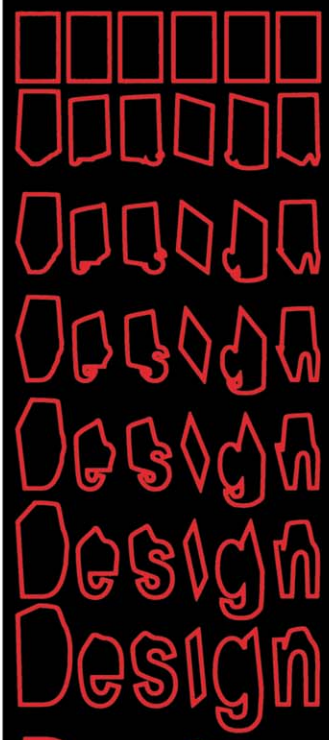
Design Knowing and Learning: Cognition in Design Education



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Chapter 1

Introduction: Bringing Design Knowing and Learning Together

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1 Introduction

The need for innovative designers has never been stronger. Industrial organizations and institutions of higher education alike recognize that as society advances, design problems increase in complexity and the kinds of expertise and experience required to create effective solutions increase as well. We are continuously learning new effects of design on our health and well-being, on the technologies supporting our future, and on our culture. Over the last decade efforts to support and enhance the practices of design professionals have evolved into what some have called a *science of design*. Finger and Dixon have grouped the resulting research into six related research areas (Finger and Dixon 83): 1) discovering and describing design processes; 2) developing prescriptive models of design activity based on best practices found in industry; 3) creating computer models of design processes; 4) developing languages and representations to support design; 5) creating analytic tools to support design; 6) developing design practices for manufacturing and life cycles. These endeavors have introduced new tools supporting design and have helped practicing designers improve their processes. It is unclear, however, what contributions these six areas have made towards advancing our understanding of design learning—how engineers, architects and software and product designers—learn the skills and knowledge to be productive and innovative.

Some design educators have tried to build on this work by advocating "guided design" as a pedagogical strategy (Wales and Stager 77). Guided design prescribes the processes that good design is to follow, providing a procedural roadmap for aspiring designers. This intuitively seems a useful method for teaching novice designers, providing a scaffold for their experience and efforts. However, preliminary empirical research does not necessarily support its effectiveness. In a small controlled study with freshman designers, Atman and Bursic (96) failed to show a statistically significant difference between a group of five who

had read a chapter from a design textbook and those who had not. In an ethnographic study of student mechanical engineering design teams, Newstetter (98) discovered that while students will overtly appear to follow prescriptive methods for a grade, covertly they discard the methods and undertake design as they see fit. This seems to be because they failed to see the relevance of the tools and methods provided by the instructor. These preliminary studies suggest that access to prescriptive design methods may not be as effective as a scaffolding device to learners of design as might be hoped. What these studies do not adequately explain, however, is why these potential aids to design learning failed. This is an example of the gap between pedagogical theory regarding design learning and strong links into the science of design; such links have yet to be forged.

In an effort to assess the status of current thinking with regard to design learning and its relation to other work in a science of design, the editors of this book sponsored a small conference at the Georgia Institute of Technology in the spring of 1999. A group of design researchers and educators were invited to campus to discuss an agenda for the development of a concerted research effort in design learning. The organizers (and editors of this book) sought to replicate the intellectual fervor and intensity of ideas that characterized the early cognitive science seminars, orchestrated by Herbert Simon at Carnegie Mellon University, in the early 1970's. To that end, we brought together people from different design fields that ordinarily would have little or no occasion to meet and exchange ideas. Architects, material science engineers, industrial designers, chemical engineers, software engineers and cognitive scientists, all deeply involved in design education pedagogy and curriculum issues, spent two days presenting position papers and exploring each others ideas. We envisioned this being the first of a series of bi-annual meetings that would initially forge and continually update a research agenda aimed at understanding how to better educate future designers. This collection of papers was commissioned as a result of that inaugural meeting.

Prior to the conference, the editors of this book had been hopeful that researchers from varied disciplines had already undertaken the needed foundational work. In order to identify and bring these efforts together in a journal format, we co-edited a special 1999 issue of *Design Studies*, which focused on design learning. Although we received more than twenty-five potential papers, we were disappointed with the submissions. Generally we found two problems. While many reported on innovative classroom techniques or interventions, few had conducted rigorous evaluations of learning, which would have indicated whether the interventions had been successful. It was unclear what had been learned and how novice understanding of design processes had changed. In addition, the suggested pedagogic strategies did not demonstrate grounding in the research conducted over the last two decades in cognitive science and educational psychology. As a result, we found that the design rationale for the classroom interventions was either poorly documented or missing altogether. We failed to see connections between the proposed

pedagogic strategies, the learning sciences, and studies of the skills and capabilities of expert designers. It was clear from this experience that a concerted effort was needed to bring the foundational activities together in a systematic way. More specifically, bringing together means to us to identify core work, identify relevant research paradigms, and identify potential research programs. This book represents an initial step towards forging those links so as develop a *science of design learning*.

2 Organization of the book

Organizing and ordering the papers collected here have been a challenging design problem in its own right. Coming from different disciplines and communities of practice, the authors and their work represent a broad spectrum of cognitive science-based approaches to understanding design knowing and learning. The intention when we invited the conference participants was to achieve a wide diversity of opinion and perspective, a laudable goal for spurring discussion but problematic when compiling an edited book. In order to achieve a sense of coherence, we asked the authors to make changes from the original papers and solicited new papers to fill perceived gaps. Of the twelve papers, ten originally served as the basis for conference talks and appeared as drafts in the conference proceedings. The Craig and Zimring papers were solicited later from two conference participants who were not presenters.

Gaining access to the cognitive processes, situational constructs and to the knowledge that comprises expert design activity poses a considerable methodological challenge. How can we develop experimental or experiential constructs and organize data collection methods that will reveal how designers solve design problems? The designers may be at various stages of development, beginners, intermediates or experts. Where should we focus our empirical lens—on the internal workings of the mind or the external artifacts that anchor and filter cognition? How can we make the internal external and how can we see what happens to the external when it moves to the internal processing of a designer's cognition? How should we treat the intermediate products of design, the jottings, the sketches, the seemingly nonsensical trappings of the mind at work? These are questions that have dogged design researchers over the last thirty years. The chapter by David Craig provides a valuable review. Craig's paper lays out four predominant research methods that have been employed by researchers to understand how designers solve design problems. These include protocol studies, content analysis studies, process isolation studies and situated studies. Craig describes each research strategy, the kinds of data resulting from the procedure and the inherent weaknesses or questions left unanswered when utilizing such an approach. Taken as a whole, the paper acts as a primer on methodologies for studying design activity at any level of expertise: beginner, newly trained or expert. Later chapters review the various work in design learning resulting from application of one of these research methods.

The next two chapters, by Atman/Turns and McCracken/Newstetter review studies that assess student progress with design, beyond examining the quality of the product. Atman/Turns used protocol studies to assess the development of student processes during small design tasks. Their chapter reviews four such studies assessing the practices of engineering design students as they progressed through their university education. The studies relied on process measures for assessing engineering design capabilities that included alternatives generated, number of criteria considered, information categories covered and transitions. They note the general improvement of students in employing these processes during their college education. They also note significant variation among beginning students when assessed on the above process measures. Their chapter ends with pointed questions regarding the educational interventions needed to enhance student capabilities.

Most studies of design, like those reviewed in the Atman/Turns chapter, assume a strong correlation between process and product. The desired process has been identified partly through protocol and case studies and also defined more prescriptively, based on the evolving design methods and design science literature (Pahl and Bietz 96). However, the strong relation between process and product is open to serious questioning. Recent studies by (Günther and Ehrlenspiel 99; von der Weth 99) point out that experienced designers often shortcut good design practices. Such results are generally disconcerting. However, experienced designers seem to effectively replace procedural knowledge with declarative knowledge that can collapse a rigorous examination into a simple "jump" directly to a solution. The assumption about the process-product correspondence is much more complex than is usually assumed. Current assumptions are open to challenge and must be studied further.

Studying novice designers is the subject of the McCracken/Newstetter paper. They show that before-after longitudinal studies do not sufficiently address important contextual aspects of a student's beginning encounters with design. They report on two years of empirical observation in the Design Learning Lab at Georgia Tech and a large-scale survey conducted in an introductory computer science course. They discuss the challenges of collecting data on novices' conceptions of design, on student's perception of design processes and on their learning outcomes. They conclude by proposing future studies needed to better understand the misconceptions that novice designers bring to design classrooms.

A background issue in design learning is what is common across all design fields. What might be taught in a generic course of design? What aspects might be transferred from one design domain to another? Three chapters address this question. First, Nigel Cross reviews the past thirty years of work using protocol analysis to assess our current understanding of design. Based on these studies, he proposes some generic strategies used in the processes

of a wide variety of design domains. He organizes these distinctive processes in terms of problem formulation, solution generation and process strategy.

Akin's chapter discusses the invariant aspects of design in relation to those aspects of architectural design that he considers variant, or unique to architecture. He identifies an architect's use of a wide variety of *analogue* graphical representations as a distinction, suggesting that these representations abstract less from the design, whereas *symbolic* representations emphasized in engineering abstract a fixed set of variables to consider. Architects also rely on *naïve* representations based on sketches and diagrams for much of their work, partly because architecture is socially situated and must respond to a variety of non-specialist stakeholders. Architects also emphasize breadth first searches of design spaces that emphasize innovation over optimized performance. Akin ends by questioning if there is a common framework of design knowledge, given the highly varied situated contexts in which different design domains operate. He suggests that this question applies within architecture, because of its constant search for stylistic innovation, as well as between it and other domains.

Zimring and Craig's chapter asks the question "what aspects of design knowledge is generic and independent of domain knowledge"? They consider various procedural aspects of designing, including ill-definedness, abduction, wicked problem solving, and design as construction. They identify counter-examples of activities that incorporate each of these activities that we would not consider design, thus raising the question whether there are any high-level processes that are truly unique to design. They end by proposing that middle-level processes, such as analogy, coherence seeking, mental simulation, dynamic modeling, argumentation, and decision making may more uniquely define design.

Identifying design's unique processes is attractive pedagogically because it suggests that there are some processes that if taught well would address the core goals of design education. However, the results of these surveys strongly suggest that there are no unique processes. Rather "design" is a socially defined activity that involves a mixture of more broadly used mental processes. It is the combining of those processes and the strategic skill in coordinating their application that seems to result in design expertise. Of course, these chapters can be interpreted in multiple ways.

If we are to understand design deeply, studies must not only map out the overall processes, but also study those processes deeply. The next four chapters attempt to examine in some depth specific processes thought to be important in design. These efforts take various positions with regard to whether the process being studied is unique to design.

The chapter by Eastman poses new questions for the study of design cognition. He proposes that the field needs to move beyond *what* designers do to *how* they do it. He poses two "how" questions. First, how are concepts that make up a design response formed? Eastman

proposes that this issue may be understood by study of the relation between external representations and mental representations, how external representations are internalized and automatized. He reviews recent work in this area and outlines possible research studies. The second "how" question is, if ill-structuredness is a central aspect of design activity, how do expert designers conceptualize the design context? Here, he reviews related work in psychology dealing with memory structures and recall processes, especially those involving analogy, that may provide a general background for addressing these questions. He then surveys three research studies in design cognition that provide new understanding of how designers gain and use their knowledge in structuring the design context.

Goldschmidt's chapter follows in a manner that takes up some of the issues raised by Eastman. She reports on previous work in mental imagery and analogical mapping, both in psychology and in the design cognition literature. She proposes that visual analogy, is a basic activity used to structure and re-structure design concepts. She reviews a recent Ph.D. thesis that studied the use of visual analogy among three different levels of architectural designers. The study suggests that two kinds of skills distinguish beginners from professional designers: domain-specific declarative knowledge that allows easy solution to the many well-defined parts of a major design, and also the ability to recognize and adapt ideas to new contexts to solve ill-defined design problems. Visual analogy seems to be a central process for adapting form concepts in innovative ways.

Vinod Goel has uniquely, to our knowledge, begun to relate the processes of design cognition to its neuroscience basis. In this chapter he reports on a patient PF, an experienced architect, who experienced a right hemisphere lesion of the prefrontal cortex. This impairment provided a unique opportunity to study the contribution of the prefrontal cortex on design behavior. He reports on PF's ability (or inability) to deal with two different kinds of design information: (1) the domain specific issues, forms and materials used in defining and solving design problems, and (2) the tacit planning and structuring processes that are needed to resolve large ill-structured design tasks. While Goel could not undertake a before-and-after study of PF's disability, he instead matched him with a control subject of similar background and skill. By tracking both PF and the control undertaking the same design task, Goel shows that the physical assault on PF's cortex led to marked inabilities to deal with the ill-structured aspects of design. While PF was well able to carry out the needed recall of criteria and issues, identifying forms and materials that make up a solution and other domain-specific declarative types of knowledge, he was not able to adequately plan or execute the detailed activities of matching criteria to actions, hierarchically organizing actions or other planning activities needed to generate a working solution. The study points out critical skills that, if missing, prohibit effective design behavior.