

Design Learning as Conceptual Change: A framework for developing a science of design learning

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Introduction

In recent years, numerous industry-oriented and education-focused initiatives have sought to prepare designers to effectively respond to increasingly complex design problems. One such initiative has been to develop a science of design. Finger and Dixon¹, in their review of mechanical engineering research, identified six ways in which researchers have advanced this project. They have developed: 1) descriptions of design processes 2) prescriptive models of design activity based on best practices of design found in industry 3) computer models of design processes 4) languages and representations 5) analysis to support design, and 6) design for manufacturing and life cycle. While these models and prescriptions have helped practicing designers improve design processes, it is not clear what contribution they have made to advancing our understanding of design learning. Some design educators drawing on this work advocate "guided design" as a pedagogic strategy². Here students follow a set of design steps and phases that mimic those of an expert designer. Although compelling as a pedagogic strategy, no empirical research has been conducted to test whether design ability develops from rigidly following a prescriptive model of design phases and activities. This is because, at present, strong links between research into the science of design, design pedagogy and theories of design learning have yet to be forged. This paper proposes a framework for bringing these three endeavors together so as to develop a *science of design learning*.

Conceptual change as a framework

A starting place for the proposed framework is the assertion that learning of any kind is filtered or interpreted through the learner's lived experiences. Such experiences, sometimes school-based, sometimes not, constitute the learner's *prior knowledge*. Research has shown that the development of an integrated and generative knowledge base depends upon the learner's prior knowledge³⁻⁵. "A well-organized and coherent knowledge base initiates inference, conceptual-ization, and the acquisition of principled understanding"⁶. It seems a certainty that prior knowledge is an essential variable in learning.

Unfortunately, however, prior knowledge is often incorrect. Various referred to as *preconceptions*⁷, *naïve theories*⁸, *alternative frameworks*⁹ and *alternative theories*¹⁰, these incorrect notions based on experiences coalesce into knowledge structures that operate in theory-like ways. As such, they have explanatory power, inform action and often resist change even when there is repeated instructional evidence that the stored information is faulty. Following Piaget who demonstrated so clearly how children and adults differ, educational researchers in the late 1970s started to probe these learner knowledge structures, particularly in the areas of mathematics and science learning, to explain the documented difficulties students have in fully grasping scientific explanations for things like bodies in motion and electrical circuitry. Since that time numerous studies have demonstrated how such misconceptions can impede effective learning. Most agree that for learning to occur, a restructuring, possibly a demolition of the knowledge base, has to occur as well. What is not agreed upon is the meaning of restructuring or the means to accomplishing it. But before tackling the nature of or means to restructuring a base of knowledge, it is important to interrogate the structure of knowledge itself.

As stated above, a learner's experiences often coalesce into a theory-like framework. A theory, as cognitive scientists conceive of it, operates as a representational system. Johnson-Laird¹¹ describes a theory as manifesting itself in three forms: 1) "propositional" representation—syntactic strings of symbolic elements (e.g. Constraint setting is a part of design) 2) "mental models"—structural analogs of real-world or imagined situations (e.g. A designer is setting constraints) 3) images—a mental model from a particular perspective (e.g. The architect is

constraining the problem). Put another way, these representations represent the “what” of the theory, “the how” of the theory and the “under what circumstances” of the theory. Theories are valuable because they shorten the interpretation and meaning-making process considerably by doing the inferential work. Humans readily develop theories to explain phenomena and cope with constant stimuli that might otherwise force them to attend more closely.

It is our contention that students come to us with misconceptions or naïve theories of design. Of critical importance to our endeavors as design educators is to discover the naïve conceptions that learners of design harbor, the sources of those misconceptions and their nature so as to anticipate the kinds of resistance we might encounter and to develop appropriate interventions that problematize these naïve theories.

Student misconceptions of design

At present we do not have systematic descriptions or accounts of design learners’ misconceptions. However, recent verbal protocol studies of novice and expert designers identify how the activities of these groups differ. In a study of industrial design engineers, Christiaans and Dorst¹² found that novices tend to scope out the problem less and seek less information than experienced designers do. At the same time, however, they decompose the problem into more solvable parts without attention to the whole design.¹ Consistent with these findings, Rowland¹³ found that novices interpreted design problems as well defined and as a result, did little elaboration to explore and close the design space. In another study of novices, Sutcliffe and Maiden¹⁴ found that while experts reason with conceptual models and rigorously test out hypotheses, novices fail to generate hypotheses or use models for reasoning. Atman et al.¹⁵ found in their comparative study of university freshman and senior designers that seniors asked for significantly more information in the problem-scoping phase, transitioned more frequently and faster between design steps and spent much longer in decision-making at the product realization stage than freshman.

Our work with novice designers in the Georgia Tech Design Learning Lab has yielded observational data that corroborates findings from the experimental studies. Although not rigorously investigated or probed at this point, we repeatedly see students engaging in the following behaviors.

- *Ideation without substance* - Students believe design is coming up with good ideas. Obviously design has ideation as a constituent element but designers also concern themselves with the realizability of ideas and evaluate ideas based on informed decision-making and analysis.
- *Design arrogance* - Students do not place their designs in the context of the environment in which the design will reside. They “arrogantly” ignore the constraints of the user (whether that is a machine or a person). They often design for themselves.
- *Design shutdown* - Students tend to focus on single point solutions to problems once beyond the ideation stage. In other words, once they have an idea, they stop considering alternatives and focus all their energy on that one solution regardless of its feasibility.
- *Design jumps* - Students have a tendency to operate at only two levels of abstraction. The highest level of general ideas (function), and the lowest level of the components of the product (structural). They do not move between these spaces in any formal manner, nor do they consider the ramifications of the giant leaps they are taking between those two levels of abstraction.
- *Design routinization* - Students act as though design were a serial/ linear process. The way they deal with design problems resembles the linear parsing of the algebra problem. Iteration, revisiting past decisions and evaluating alternatives is not in their process model.

These preliminary findings on learner misconceptions of design suggest that we need to attend to two things: 1) how learners conceive of design; 2) how they undertake design. In philosophical terms¹ our concern should be with their *ontological* and *methodological* conceptions of design. We have data on the latter but not on the former. And yet, method follows from ontological beliefs. [A science of design learning needs to target both.](#)

Our hunch, not yet tested or verified using sanctioned methods from cognitive science, is that students have developed theories about the nature of design that conflict with theories held by expert designers. These theories, in turn, wrongly inform their activities. Where do these theories come from? They come from childhood experiences

¹ I am indebted to Nancy Nersessian for helping me distinguish between these two types of understanding.

building with blocks, constructing forts out of tablecloths and card tables, from assembling dioramas for class projects. They are also crafted from years of school problem solving where there is one sanctioned route and one answer to the problem. Students often solve design problems as though they were algorithms to be parsed. In English classes, it is not uncommon for students to practice design as brainstorm-ing. In this context, it is generating novel ideas. Student theories of design also come from media images of designed products, from fashion to cosmetics to cars. Design here is most often depicted as the creation of consumer products.

In our classes, we have collected learner concept maps of design as a source of data for developing our understanding of learner misconceptions. The directions ask them to draw a representation of the design process using the words they associate with design. We have found that these renderings of design are prophetic in anticipating the kinds of behaviors we have seen students engage in. Two particularly insightful ones are featured below.

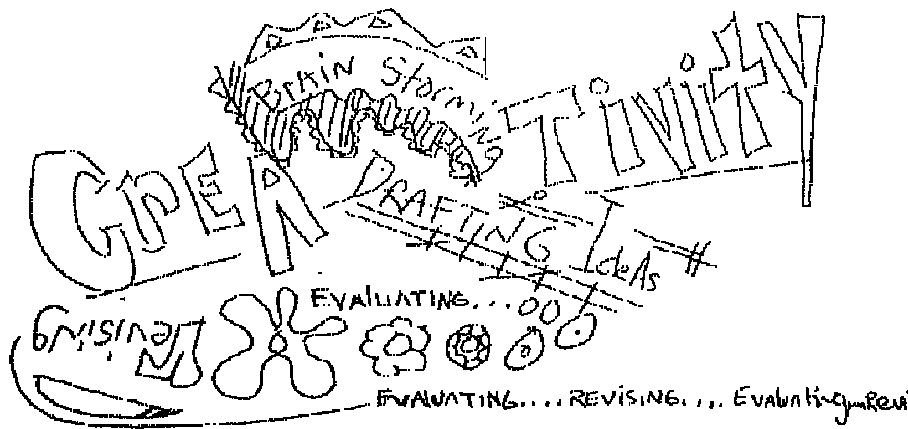


Figure 1

Figure one constructs design as creative brainstorming and idea generation. Evaluating and revising are peripheral to the central, larger than life activity of creating ideas. Using Johnson-Laird's notion of theory, we could say that this student's propositional representation of design is quite impoverished. Design consists of only five elements: creativity, brainstorming, drafting ideas, evaluating and revising. The mental model foregrounds the role of creativity while diminishing the importance of evaluation and revision. This naïve theory mirrors the popular image of design being a stroke of genius, the gift of a talented few. It is an image from the arts, and not without credibility where creative genius is the hallmark of design success. One problem with this theory is that creativity holds up the whole house of cards; without it, design fails.

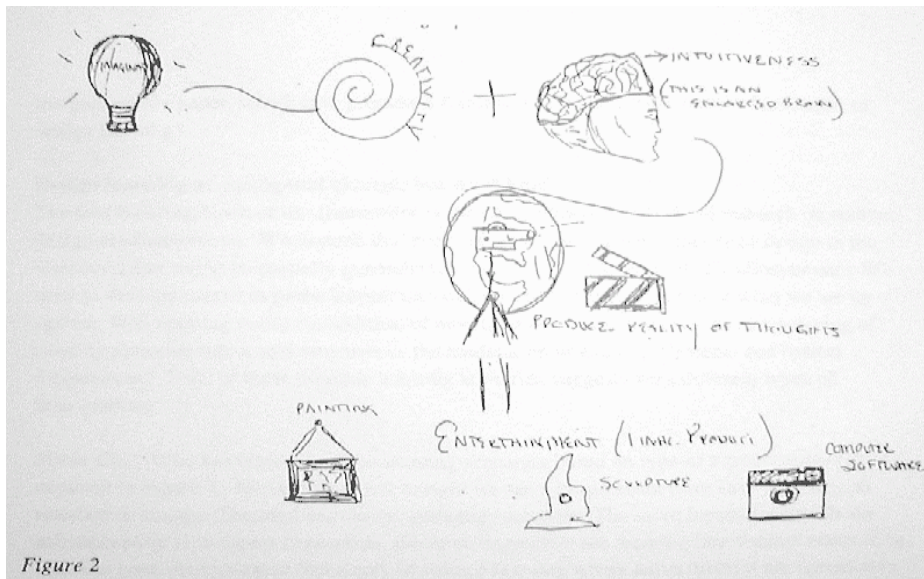


Figure 2

In Figure two, we again see the centrality of the creative process. It entails three steps that magically produces “reality of thoughts” which materialize unto various kinds of products. Propositionally we see five elements: imagination, creativity, intuitiveness, thoughts and products (of various kinds). The mental model suggested by the depiction hints at levels or phases in the process, the first in the head, the next somewhere in reality and the last as market-able products. The popular image of the illuminating light bulb for imagination renders design as that blaze of creative light that strikes some and not others. The symbols at the bottom begin to suggest Johnson-Laird’s image representations where design occurs in the arts and in computer software. Intriguing, as these images of design are, what implications do they have for the goal of this paper, which is to propose a framework for the development of a science of design learning?

Design learning as conceptual change, but what kind?

The first building block of our framework is the development of a body of research on student design misconceptions. We assume that every student brings a naïve theory of design to the classroom that might be partially generalizable across students and partially idiosyncratic. We need to develop means to probe learner misconceptions, to better understand what we are up against. Will learning entail the addition of new propositional elements, the restructuring of existing elements into a new structure or the eradication of existing elements and radical replacement? Each of these possible learning scenarios suggests very different types of interventions.

Chi has identified three learning scenarios based on type of misconception shown in Figure 3. Moving from left to right we see a progression from easy to change to resistant to change. The implications for pedagogy are clear. The more *incommensurable* the misconception is to expert conception, the more aggressive the learning intervention needs to be. This has been demonstrated repeatedly in science learning where naïve theories are remarkably robust and resistant to change regardless of the pedagogy.

Chi, M. Talk at Tech 1998

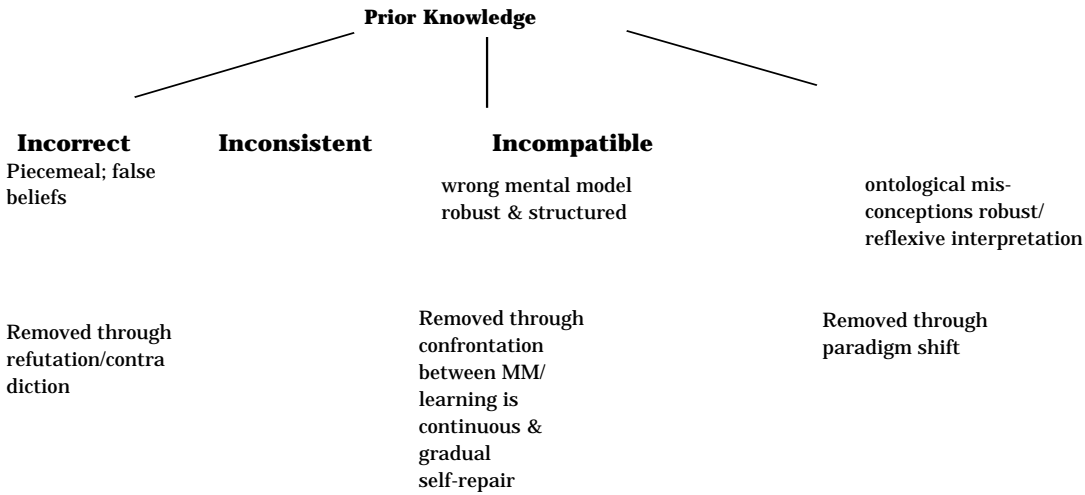


Figure 3

At present, our hunch is that students harbor inconsistent conceptions of design, which means that our pedagogic practices must bring about a confrontation between the learner model and the expert model. Having students follow prescriptive models of design, we believe, does not constitute confrontation of the sort that can begin the dismantling of the mental model. Students are masters of following teacher tasks with out learning them as ways of doing¹⁶, just like science learners can parrot back the laws governing bodies in motion on a test but cannot explain why an object moves as it does in real-time. So the second pillar of our proposed science of design learning is the development of pedagogic practices based on our understanding of the nature of learner misconceptions. The partial framework is illustrated in Figure 4.

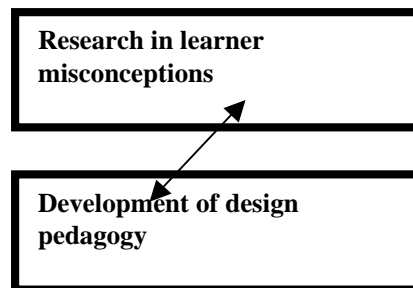
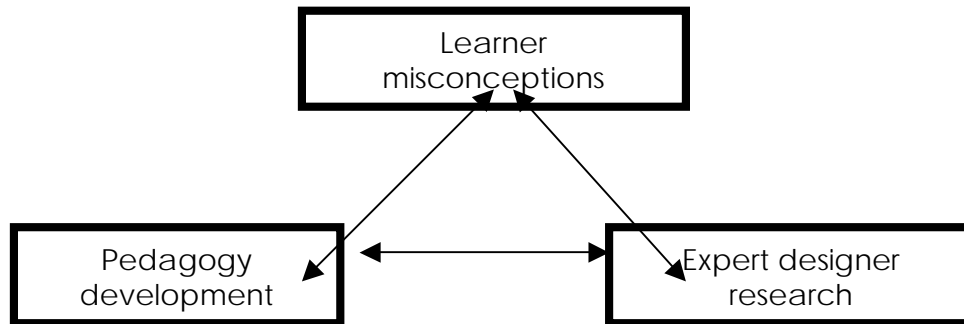


Figure 4

Our framework requires continual shuttling between the two activities of refining our understanding of learner misconceptions and defining the pedagogy that takes on those misconceptions. The first goal should be to better understand *the nature of conceptual change* needed to apprentice learners to effective design practices. We need to determine the form and robustness of learners' prior knowledge to know what kinds of interventions are appropriate. This means local, in-class experiments or what Brown¹⁷ calls "design experiments" situated in real classrooms. Classroom activities should be designed to both build on the strengths of the learner model and to change the weaknesses.

The final pillar of our framework is continued research in the cognition and practices of expert designers. The more we understand the ontology and methodology of practicing designers, the better we can identify the differences between novices and experts. And further, the more we understand the learning goals we are seeking to achieve, the

better we can craft a pedagogy that help students achieve those goals. So, for example, if from ethnographic studies such as Bucciarelli's¹⁸ we find that socially inscribed tools are crucial in mediating design activity, then we must develop a pedagogy that apprentices students to the use of such inscriptional systems. Our final framework is depicted below. The three activities are in a dialogic relationship, influencing and being influenced by the others.



Conclusion

Our understanding of design cognition has grown considerably over the last fifteen years. At the same time, those associated with the design disciplines, from engineering to architecture, have recognized the importance of developing sound educational practices to educate the next generation of designers critical to competing in a global economy. ABET has moved design from the periphery of engineering education to a more central position requiring engineering institutions to infuse curricula with more design opportunities. However, it is imperative that the educational interventions aimed at teaching sound design practices proliferating throughout this country be informed by rigorous and extensive cognitive science research on learner prior knowledge, the developmental or evolutionary stages learners might transition through and the challenges attendant on each. Without this, design education has no hope of evolving into a science of design learning.

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