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David H. Jonassen
University of Missouri - Columbia

How do design problems vary?

Are there different kinds of design problems? According to Brown and Chandrasekaran (1989), Class 1 design problems are open-ended, non-routine creative activities where the goals are ill-structured, and there is no effective design plan specifying the sequence of actions to take in producing a design model. Class 2 problems use existing, well-developed design and decomposition plans (e.g. designing a new automobile). Class 3 designs are routine where design and decomposition plans are known as well as customary actions taken to deal with failures (e.g., writing a computer program).

Jonassen (2011) argued that problems vary in terms of structuredness, complexity, and context. On the structuredness and complexity continua, design problems tend to be the most ill-structured and complex. Brown and Chandrasekaran suggest that design problems may vary along a continuum from well-structured to ill-structured, depending upon the context in which they are solved. In formal, school contexts, design problems are often more constrained, allowing many fewer degrees of freedom in their representations, processes, or solutions and are therefore more well-structured.

McKenna and Hutchison (2008) reported a study in which undergraduate engineering students solved two design problems: one well-structured and one ill-structured. The well-structured problem was consistent with those typically presented to students in freshman design seminars and high school design assignments:

Develop a device that:

–Can cool six-12 ounce beverage to < 40 °F in under five minutes
–Is portable
–Able to cool 30 beverages
–Cost of building material is less than $30

Although several solutions exist, this problem is fairly well-structured because of the pre-defined constraints which restrict the problem space and the range of allowable solutions. Such problems are conceptually classifiable (heat transfer), which constrains solutions and solution methods even more.

The ill-structured problem that they presented to engineering students was:

Design assistance for a Government Health Organization (GHO):

–GHO is working to combat mother-to-child HIV transmission
–HIV can be passed through breast milk
–Mothers insist on breastfeeding to avoid being labeled by disease

This problem is more ill-structured because the goals and constraints are not defined. The solution depends on psychological beliefs and personal opinions, making it less predictable. That is, there are a large number of solutions, and assessing the effectiveness of alternatives would rely on unstated and under-specified criteria.

Context also plays an important role in specifying the nature of design problems. In formal classrooms, it is important that problem solutions can be evaluated on stated criteria, because that is a cultural expectation in classroom instruction. Such expectations are not relevant when assessing everyday workplace problems. Workplace engineering problems, for example, tend to be ill-structured and complex because they possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, and collaborative activity systems, where the importance of experience and the use of multiple forms of representation are required (Jonassen, Strobel & Lee, 2006).

What Kinds of Problems Should Students Solve?

Students in high school and university are inured to assignments with convergent answers and established evaluation criteria. Because of that, their learning strategies tend to focus on finding the right answer. When well-structured problems are presented to engineering students, McKenna and Hutchison (2008) found that students conducted deeper searches for information related to the problem, made increased use of connections to prior learning, and were more directed in their learning. However, with ill-structured problems, students made fewer attempts to learn about problem, made fewer connections to prior learning, and made more ambiguous searches for information related to the problem. In short, they were uncertain about how to approach the problem.

Jonassen, Khanna, and Winholtz (2011) implemented a problem-based version of a materials science course in the mechanical engineering curriculum. In the course, students expressed considerable confusion about the way the course was structured around problems rather than topics, so they perceived the course as lacking structure. Although most of the students described their experiences with team members as positive, they collaborated ineffectively. Perhaps the most significant difficulty among the students related to the expectations of the course. While the students understood the relevance of the problems, they remained committed to the content-based exams. There was a significant disconnect between the methods that students used to study for the problems and those used to study for the exams, so traditional exams were eliminated in the second implementation. The course instructors found it difficult to provide timely feedback to students on their performance on the problems. These studies would suggest that high school and university students are ill-prepared for solving ill-structured problems.

However, contradictory evidence is provided by a series of studies by Kapur (2008, 2010, in press). He presented groups of students with well-structured problems and others with ill-structured problems in mathematics and physics. The students solving more complex and ill-structured problems without assistance experienced frustration while other groups received teacher-directed facilitation. Despite appearing to fail in their problem-solving efforts, the unsupported students solving the ill-structured problems significantly outperformed their counterparts on both the well-structured and higher-order transfer problems. Although frustrating, it appears that the productive failure approach engaged deeper level learning and problem solving in students.

To what degree are high school students able to conceptualize and resolve design challenges that include a number of complex variables or choices? That issue has not been informed by a lot of research. Clearly, motivation will play a significant role in student efforts to solve more complex and ill-structured problems. High school and college students have learned that most problems have correct answers, which becomes their exclusive goal preventing them from approaching ill-structured problems successfully. Our experiences in several studies in physics and engineering suggest that the correct answer is much more important than understanding the problem or transferring the skills required to solve it. Those expectations will need to be changed and the required efforts need to be scaffolded.

How to Teach Design Problem Solving

Research in problem solving has most often sought the one best method for solving all kinds of problems. If we accept that different kinds of problems exist (Jonassen, 2000), then such an assumption is untenable. Design problem solving is addressed primarily in engineering design, product design, and instructional design. Most researchers have posited normative models for learning to solve design problems. For example, Dym and Little (2004) assert that solving engineering design problems involves the following processes:

1. *Problem definition*: from the client statement, clarify objectives, establish user requirements, identify constraints, and establish functions of product by providing a list of attributes
2. In *conceptual design* phase, establish design specifications and generate alternatives
3. In the *preliminary design*, create model of design and test and evaluate the conceptual design by creating morphological charts or decision matrices (See Chapter 3)
4. During the *detailed design*, refine and optimize the chosen design
5. For the *final design*, document and communicate the fabrication specifications and the justifications for the final design

If we accept that this or any model of design problem solving adequately captures the process for solving even a category of design problems, then these processes may be modeled or scaffolded for students during learning.

For purposes of learning how to design, Jonassen (2011) has argued that design problem solving can be represented as a series of decisions (see Figure 1). Those design decisions are based on multiple constraints and constraint operations in the design space. At the beginning of the design process, functional specifications and initial constraints are specified by some sort of needs analysis process. Designers then begin to refine the problem space by making decisions. The solution to each decision depends on what kind of decision it is, additional constraints that have been introduced into the problem, and whatever beliefs are held by the designer.

Most designers and problem solvers have preferred solutions to problems. In order to counteract those beliefs and biases, each design decision should be articulated by learners, who should be required to construct an argument in support of their decisions. With each cycle of decision making, the problem space narrows (deceasing spiral in Figure 1). That is, degrees of freedom in related decisions decrease and the solution becomes better defined. So, design problem solving should require learners to conduct some needs analysis in order to specify initial constraints and goal, followed by cycles of decision making where learners identify alternative solutions to each decision and construct an argument to support their decisions. The quality of the argument should be judged by the quality of the evidence used to support the decisions as well as counterarguments rebutting alternative solutions (Jonassen & Kim, 2010).

The design problem space is usually represented as a model. That is, design is also a process of model building as well as decision making. As design decisions are made, designers begin to construct sketches that morph into models that morph into prototypes (see Figure 1). Engineers and architects most often begin by creating a drawing. As decisions are made about the design, the design model expands as the decision-making contracts (see Figure 1). The initial drawing may be converted to a CAD drawing, a computational model, or a 3-dimensional model. Instructional designers may begin by producing a storyboard and later converting that into a prototype of the learning environments. These models should reflect the functional requirements of the design as elaborated during the cycles of decisions.

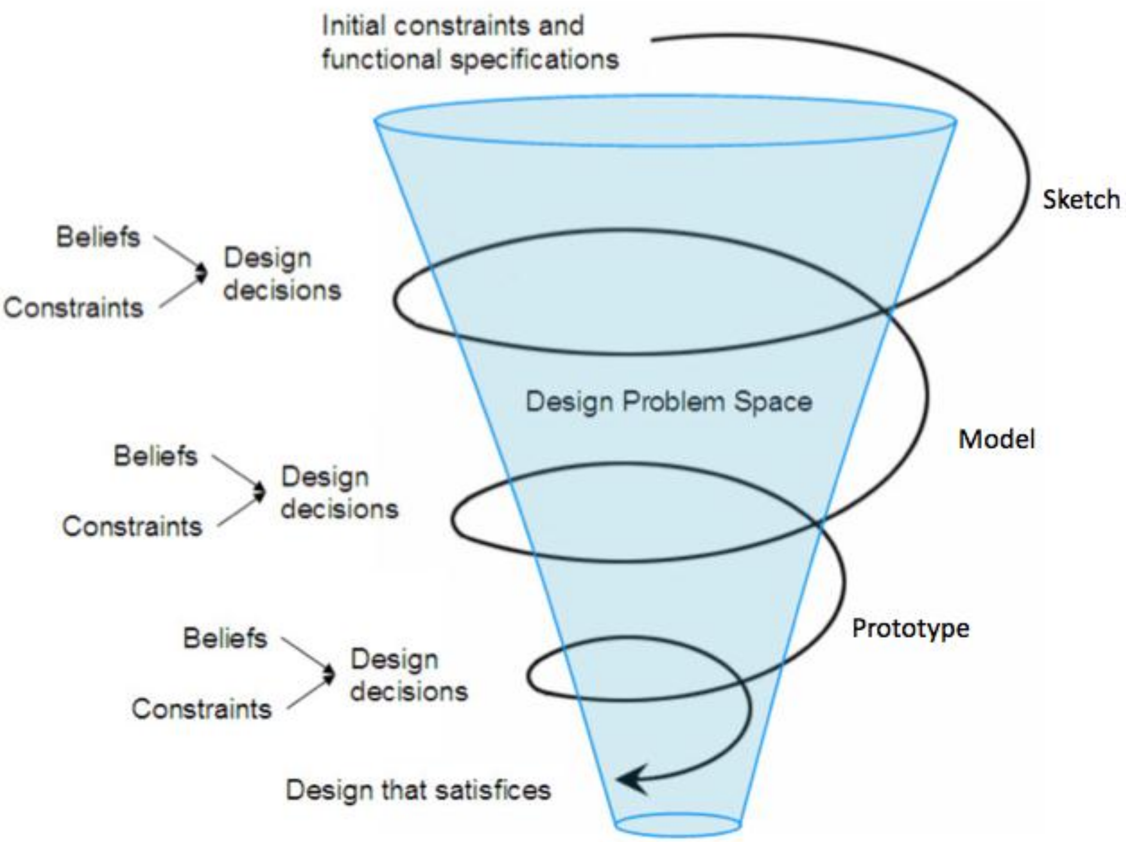

Figure1. Iterative design process.

Despite the putative goal of optimization, most workplace design processes usually end when a satisfactory solution is defined. That is, the goal of design is satisficing (Simon, 1955), not optimization. Simon coined the term to describe decisions in which satisfactory solutions that suffice rather than optimize are acceptable. Although designers talk about optimization, design solutions are seldom, if ever, the best solutions (Marston & Mistree, 1997). In everyday, workplace problems, designers are usually unable to articulate what an optimal solution is. The most commonly cited solution criteria noted by practicing engineers was "under budget and on time" (Jonassen et al., 2006).

So my recommendation for supporting engineering design problem solving among high school and university students is to present initial specifications and goals, and then require learners to analyze the problem in order to identify additional constraints. Learners then begin to make design decisions and to construct a model that reflects those decisions. For each decision, students construct arguments supporting their solutions. With each set of design decisions, the mode becomes more elaborate as the problem space becomes more circumscribed. The final decision is when does the design satisfice?

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