AC 2010-567: THE IMPORTANCE OF PROBLEM INTERPRETATION FOR ENGINEERING STUDENTS

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The Importance of Problem Interpretation for Engineering Students

Abstract

This study used Verbal Protocol Analysis (VPA) to investigate the cognitive process of 8 undergraduate engineering students during a hands-on model building design task. The present paper will focus on one aspect that emerged from this research: the paramount importance of correctly interpreting the problem. Although this may seem simplistic, correctly framing or interpreting the problem (which is distinct from identifying the problem) was a crucial and pivotal point for these students. Without it, the developmental process stalled and the design path became more haphazard. Once students were able to correctly interpret the problem, their path to a viable solution progressed much more smoothly and efficiently.

Introduction

Understanding how and if engineering students are utilizing the engineering design process (EDP) is important in order to understand and implement effective teaching of design courses**.** The obvious first step in any engineering design task is identifying the problem or need; a bridge washes out, garbage bins are needed for a train, an amputee needs a more comfortable leg brace. However, there needs to be a distinction made between identifying the need and interpreting the problem. Interpreting the problem is the interface between identifying the need and developing a viable solution. If addressing the issue of a town becoming inaccessible during the rainy season when its only bridge washes out, some interpretations of the problem might be that the bridge is not strong enough, there is too much water with no place to go, or the town is geographically too vulnerable. These various perspectives might all lead to good solutions, but how an engineer interprets or frames the problem informs the approaches taken and influences the solution. While identifying the need may be fairly straightforward or obvious, interpreting the problem can be much more obscure. Pahl[1] noted a decade ago that good solutions come from a thorough analysis and clarification of the task. Are engineering students learning this task clarification or problem interpretation? What factors do engineering students consider during the EDP?

Literature review

A number of studies have focused on problem interpretation. In a meta-analysis of 40 studies of the design process, Mehalik and Schunn[2] discussed how problem representation is one of the elements of the EDP. How a problem is construed has an impact on what aspects of a design are emphasized and on the solution paths chosen. They also noted that more experienced designers tended to spend more time exploring and analyzing the problem than inexperienced designers.

Ill-structured problems are often a mixture of people, institutions, artifacts, and nature, making for a complex system that could lead to half-solved problems or even solving the wrong problem. Framing the problem correctly, particularly ill-structured ones, is fundamental to its' solution. [3] For example, in studying the design strategies of experts, Cross and Clayburn Cross noted the importance of problem framing during the design task of attaching a backpack to a bicycle. In designing a frame for a backpack, their expert designer interpreted the problem not as one concerning the attachment, but as one of stability between rider, bicycle, and backpack.

While some have emphasized the importance of correct problem framing, others have emphasized the role of problem finding, particularly when problems are ill-defined and solutions cannot be reached through the rote application of knowledge or experience. Developing a creative solution is often a matter of problem restructuring (rather than merely accepting the problem as given) by reorganizing existing knowledge or transforming concepts. [5-8] Since restructuring problems and perspectives could lead to new problem interpretations and solutions, designers may intentionally restructure a problem to be ill-defined as a creative step in problem solving. [6, 9]

There are many common characteristics between models of the EDP from both industry and academia. Although some models have more steps than others and the sequence of steps may not be identical, many of the steps are quite similar. Most engineering design process models also recognize iterative or feedback loops. A brief compilation of models of the engineering design process can be seen in Table 1. It is interesting to note that identifying the need, researching requirements, and developing solutions are clearly necessary steps across the various models, yet none consider “Interpreting the Problem” (which can be much more difficult than “Identifying the problem”) as a necessary component.

Our research question is, “Do engineering students effectively interpret the design task?” With no a-priori assumptions, we investigated how engineering students proceed through the EDP via a hands-on, model building task.

Methodology

Because we cannot view cognitive processes, one way to know what people are thinking during a design task is to simply ask them. One method that employs this tactic, and has been used to advance our understanding of the cognitive processes of engineering students during a design task, is Verbal Protocol Analysis (VPA). During VPA data collection, subjects are asked to think aloud while performing a task [19]. This form of data collection does not assume that subjects have access to their cognitive processes, but they are able to report the contents of short-term memory. From these verbal reports, we can gain insights into how subjects generate and transform information about the problem, and how they go about developing a solution.

Verbal Protocol Analysis has been used extensively since the 1970’s to study the cognitive processes of engineering students [20- 23] as well as experienced designers. [6, 24, 25] Although VPA is considered the most appropriate method to study the cognitive abilities and processes of designers, it is not an assessment tool appropriate for large subject populations due to the copious amount of time required for analysis. [6, 26, 27] For this paper, the verbal reports of eight student participants were analyzed.

MA Dept. of Education[10]	MIT Civil & Env. Engineering[11]	NASA[12]	OH Dept. of Education[13]	U. of AZ Dept. of Sys. & Ind. Engineering[14]	Purdue EPICS[15]	Nat'l Science Teachers Assoc.[16]	Atlantic Canada Dept. of Education[17]	U. of CO Boulder College of Engineering[18]
Identify need/problem	Understand problem	Identify the problem	Identify the problem	Customer need	Project identification	Define problem/ need	Opportunities	Problem identification
			Brainstorm				Design Brief	Forming ideas
Research the need	Information	Identify constraints	Investigate Research	Design requirements	Specification development	Research Investigate	Investigate Research	
	Feasibility							Feasibility
Develop possible solutions	Select/Design alternatives	Brainstorm solutions/ Ideas	Generate multiple solutions	Design model	Conceptual design	Propose design solutions	Generate options	Conceptual design
		Explore possibilities				Analyze Evaluate		Preliminary design
Select best solution	Select final solution	Select an approach	Choose best solution		Detailed design	Select & test	Select best option	Final design
Construct a prototype	Build/ Prototype	Build a prototype	Build model/ prototype	Build model	Delivery/ prototype	Proof of concept	Develop solution	Build and test
Test and evaluate	Test/Monitor		Test and evaluate	Validate model	Evaluate		Evaluate	
Communicate the solution				Design review				
Redesign		Refine the design	Redesign/ improve	Redesign/refine requirement	Refine/ redesign	Modify/ redesign	Redesign	Re-engineer

Table 1. Models of the Engineering design process

Subjects

Eight students attending a private New England university were asked to participate in a design task at the end of the school year. There were five males and three females from diverse engineering disciplines and academic years (See Table 2). It was a sample of convenience as the students were all known by one of the co-authors. Each participant was given a code according to gender (M, F), engineering discipline (chemical, mechanical, ect), and Class Level (2 = sophomore, 3 = junior, 4 = senior).

Table 2. Study Participants

Participant Code	Gender	Engineering Discipline	Class Level (undergrad)
M-ChE-2	M	Chemical Engineering	2
M-EE-3	M	Electrical Engineering	3
M-GE-4	M	General Engineering	4
M-ME-3	M	Mechanical Engineering	3
M-ME-4	M	Mechanical Engineering	4
F-EnE-4	F	Environmental Engineering	4
F-CE-4	F	Civil Engineering	4
F-ME-4	F	Mechanical Engineering	4

Procedure

The task used for this study was to design and construct a prototype one-handed jar opener, i.e., a jar opener for people that had the use of only one hand. The procedure was beta-tested with an engineer and several engineering students, and modifications to the task were made based on their comments. The study participants were asked directly via e-mail if they would be willing to participate in a research experiment on engineering design. After giving consent, students were tested individually in a small conference room on campus. A small audio and video recording device was mounted on the ceiling to record both speech as well as students' hands during the task. (In accordance with IRB requirements, faces could not be seen in order to maintain participant anonymity.) Before recording began, the participants were told the purpose of the study, which was to look at the design process of engineering students, and given a practice think-aloud project that required them to assemble a 24-piece puzzle. When the participants finished the puzzle, they were given an information sheet that explained the design task: Develop a jar opener for individuals that had the use of only one hand.

Laid out on a large table were 15 sets of cards listing activities that the students could choose to do. The card activities were titled: *(1) Talk to Jim (an amputee), (2) Speak with Mary (a stroke* *victim), (3) Learn about amputees, (4) Learn about stroke, (5) Look at other models, (6) Plan/draw/sketch, (7) View available materials, (8) Build a prototype (9) Review first principles of physics, (10) Talk to jar manufacturers, (11) Examine elementary mechanics, (12) Read technical descriptions of prototype jar openers, (13) Look at jar variables, (14) Investigate aesthetic options, and (15) View unnecessary nonsense.* Each activity set was made up of five to twelve cards that offered various pieces of information. In general, information in the first 7 choices listed was deemed by the research team to be more helpful than the information in the last 7 choices (although all the card choices contained some superfluous information).

The information sheet instructed the participants to choose whichever activities they thought might help them formulate a solution. The purpose of offering the diverse choices was to observe if students could cull the important information needed to solve the design task. When participants completed the design task, they were asked to write a short reflection paper of their experience. Photos were taken of their prototypes.

LEGO® pieces were used in building the prototype. When subjects chose the *Build a prototype* card, they were handed a kit of LEGO pieces and instructed to use the pieces simply to get their idea across, and not be overly concerned with any challenges arising from the materials. While the functionality of the pieces did not allow for heavy force to be used in opening a jar, the fact that the pieces could be assembled, taken apart, and reassembled quickly and easily outweighed this disadvantage. In addition, due to their long standing popularity, most students were at least somewhat familiar with LEGO pieces.

Data Analysis

The transcribed texts with time stamping formed the main data for analysis. A rich representation of thoughts can be formed by identifying similar patterns in the repertoires used during the design process [28-29]. We analyzed the design path these engineering students took during the EDP. One element that emerged from this data was that each of these students had a moment where they seemed to "discover" their solution, when all the pieces of information they had been gathering and all the ideas they had been considering seemed to coalesce, resulting in an understanding of how they would develop their prototype solution. This pivotal point, when they correctly interpreted the problem, was crucial to their design process.

<u>Example 1: M-ME-4</u>
This student followed a somewhat circuitous path. After reading a few sets of cards, he began to draw his design: A U-shaped lever to go over the top of a jar to seal it (similar to a mason jar). So his first interpretation of the problem was one of sealing the jar (as opposed to opening it). (Time in minutes:seconds precedes verbal accounts)

> *(6:27) I'm not really worried about the bottom of the jar, um. I'm more worried about the top of the jar.*
> *(9:00) That's going to be the lid. And then you have to find a way to seal it down with perhaps like an 0-ring or something that would, you know, provide a seal 'cause jars are pretty much used for, you know, your liquid containment.*

His next interpretation of the problem was to redesign jars.

(21:49) The problem with this prototype is that it requires, um, it requires redesigning jars in general.
(22:02) I mean you could talk to the manufacturers of jars, see if you could get them to change their design.
(23:00) This requires a redesign of jars in general.

But he eventually realized his initial ideas were not viable solutions, and had his “ah-ha” moment when he correctly interpreted the problem:

(23:12) So we got our cylindrical jar and it’s gonna require being twisted. What you need is something that can be stationary and grip the jar, while they twist the jar.
(23:51) It can make it so that you need to take the two ranges of motion, the two directions of motion . . . and make it into something they can do with a singular movement.

Once he correctly interpreted the problem, the solution came quickly:

(24:47) I’m thinking of an oil filter wrench.

An oil-filter wrench type device was precisely what this student built (Figure 1).

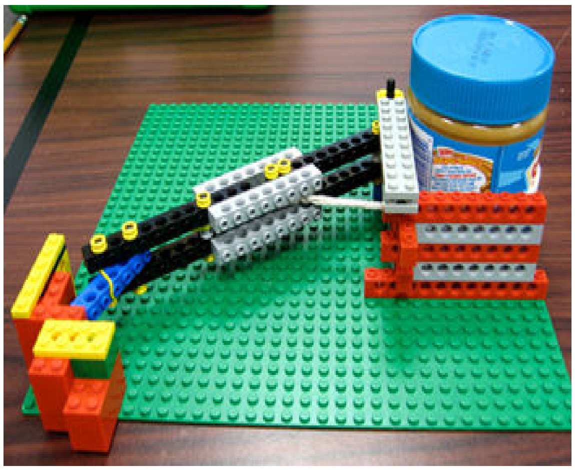

Figure 1. Prototype for M-ME-4

This student struggled at first and although he did research and gather information, his EDP was awkward. He spoke of sealing the lid, making a mason-type jar attachment, and redesigning jars. His solutions to these interpretations of the problem clearly were not effective. However, once he correctly interpreted the problem (to keep the jar stationery so clients can turn the lid), his design path was more straightforward and efficient. Although designing often has an element of ambiguity with many complex factors and constraints to consider, correctly interpreting the problem was a pivotal turning point in his EDP.

Example 2: M-ChE-2

Our sample of student designers defined the criteria, collected information, looked at materials, and considered ideas and possibilities. But once a student articulated a correct problem interpretation, the developmental path to a solution was much more direct and straightforward, as was demonstrated by M-ChE-2. His initial focus was on torque and he wanted to:

(16:36) Come down on the cap and involve serious torque somehow.
(24:46) Gears and spring type objects . . . to decrease the force . . . that actually is necessary.

(26:30) I think it'd be best for them to turn something to be able to decrease that torque.
But as he gathered more information, he considered other characteristics to include in his solution:

(19:51) That would be important, having a spring.
(23:19) Should probably want a pretty strong like, cap to go on top . . . something that's very durable, but on the inside (it) would actually be touching the jar.
(23:33) Probably something a lit bit softer, stretchy, and flexible . . . like rubber.
(24:25) I want something for the jar to be able to be in . . . that would hold it.
(28:00) Gripping mats. Yeah, that'd be important.

This student was evaluating ideas and considering various characteristics. But it was the correct problem interpretation that helped galvanize his ideas:

(29:15) So the thing is about holding it still while turning.
(29:20) So maybe it'd just be, just as good, to make a design that just, at least holds it in place.

This design problem did have an element of torque, and gripping mats are materials most students are familiar with to prevent jars from slipping. However, as soon as this student articulated, "holding it still," all the elements that he had been considering came together. It was at this point that he began sketching out his idea and, as can be seen from Figure 2, his solution did have a component for the jar to sit in, with gears to make the base adjustable.

Figure 2. Prototype for M-ChE-2

While this student took almost a half hour to reach the correct problem interpretation, others focused in much more quickly, as demonstrated by the following example.

Example 3: F-EnE-4

This student perused the other prototypes and evaluated the characteristics of each:

(9:11) Just looking at these examples.
(9:28) There's no grip.
(9:39) That funnel attached at least has a wheel to turn.
(9:51) I don't think that's gonna work.
(9:55) This has some friction under the peanut butter jar.
(10:12) I like the idea of having something holding.

After looking over the prototype models, she was able to quickly evaluate what was needed to solve the problem.

(11:33) Friction is a good idea.
(12:11) So I like the friction, I like the holding and then something needs to clamp on to the top of the lid and allow you to turn it.

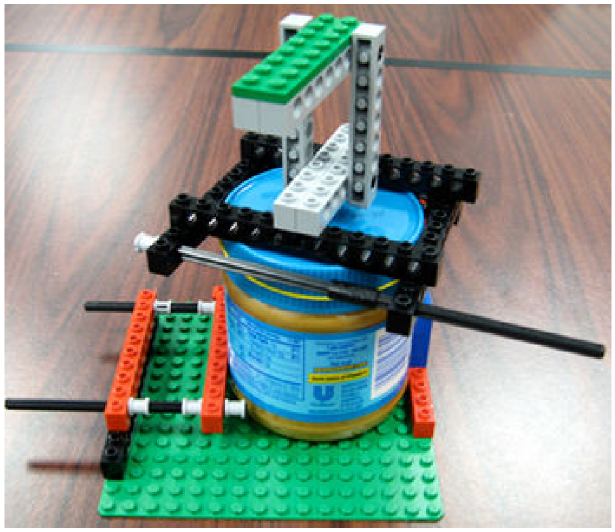

Figure 3. Prototype of F-EnE-4

As you can see from Figure 3, this student designed a very nice prototype with an adjustable base to accommodate different sized jars, and an adjustable attachment to clamp on top of the jar. Correctly interpreting the problem is crucial in reaching a final solution. Without this step, the EDP cannot progress. This is illustrated in the following example.

<u>Example 4: F-CE-4</u>
Like others, this student considered various ideas and characteristics but she seemed to fixate on one particular characteristic:

(10:55) I would use the long lever arm.
(12:49) If you're using a long lever arm, that should be simple enough.
(27:32) You'd want a long lever arm that you just kind of push.

This student did consider other attributes:

(20:20) I guess the gears would make it easier for people to rotate.
(20:52) I guess you could use the bricks to keep the jar in place . . . and you can move them around.
(23:04) I'd have the cone at the bottom and this would be some type of screw type device.
(24:15) I can do the other thing where you just push the can up into a holder and make sure it fits tightly enough.
(24:33) Or for that matter, why can't you just clamp the jar down and then use your hand?
(26:24) I don't know how I'd incorporate a funnel idea.
(32:58) You want to make sure that whatever you're clamping onto the top, uh, has some sort of friction pad to make sure that it doesn't slip.

This student alluded to a correct interpretation of the problem, but did not recognize it as "finding the problem" and continued to search for ideas:

(34:43) I guess you want to provide some lateral support.

(36:51) I would want a heavy base, like a super heavy base.
(37:41) So, you could also have a cone on the base.
(38:26) I like the top cone idea.
(40:19) You could hold the top and rotate the bottom.
(41:48) I guess I can figure out how to use a gear.
(45:53) You can have this post be adjustable somehow.

Although this student had the right idea in that some part of her artifact was going to have to hold some part of the jar stable, she never reached a clear interpretation of the problem and was not able to explicitly articulate, “Something needs to clamp onto the jar to keep it from rotating.” She could not select and develop a specific design solution. The closest she came to interpreting the problem was:

(50:21) So somehow, you just like, keep it there (places the jar on a base plate).

Almost an hour into the project, this student still had no clear idea regarding a solution. She began building a prototype without direction and incorporated much in the way of opportunistic behavior (e.g., “There’s lots of wheels [in the LEGO kit] so I’m wondering if I could use wheels somehow”).

Discussion

The engineering design process begins with the identification of a need or problem. However, engineering design problems are open-ended, leading to goals and constraints that are often ill-defined. Although there are numerous routes through the design process and various approaches have the potential to lead to good solutions, how a designer interprets the problem informs the approaches taken. Therefore, the designer must first find or interpret the problem, rather than simply accept the problem as it is given.

How participants framed the problem informed their solution. The M-EE-3 framed the problem as “making something to hold the jar very effectively, and looking at the available materials.” This student built a sturdy corral that could be stuffed with small rubber tires that would hold the jar firmly against the walls of the corral. The F-ME-4 saw the problem as, “locking the top in place as they turn the bottom.” This student clamped a bar over the lid of the jar and had the jar rest on a handled tire that could be rotated. These different perspectives led to very different solutions, but the one element they shared was a correct and unequivocal interpretation of the design problem.

The design problem given in this task was to open a jar with one hand. To reach a solution, the student needed to interpret this problem and explicitly articulate, “Something needs to hold the jar, or one part of the jar stationery.” This seems simplistic in theory, but its application proved to be much more problematic as students struggled to reach this point.

The F-CE-4 could not correctly interpret the problem and struggled through the design task. The M-ME-3 interpreted the problem as “breaking the seal to pop the lid.” This was an incomplete evaluation of the problem (leading to a solution that would require 2 hands). As can be seen in Figure 4, he designed a “seal popper” but did not address how the bottom of the jar was to be kept stationary. He finished the task very quickly, in only 38 minutes, which might have been a factor in preventing him from achieving a more thorough analysis and correct interpretation of the problem.

Figure 4. Prototype of M-ME-3

It is interesting to note that design behavior did not vary across engineering majors. All eight students properly began the EDP by searching for information, considered ideas and characteristics, and evaluated possibilities. Each student at some point struggled and had moments of frustration. But for most students, there was a clear and specific moment of insight when all their ideas galvanized, leading to their potential solution. This moment occurred when they discovered and recognized a correct interpretation of the problem. For example:

- *So the thing is about holding it still while turning.* (M-ChE-2)
- *The things we need are some sort of base to stabilize the jar, and then some way to lock it in, and then a third component to turn, to turn the lid.* (M-ME-4)
- *I like the friction. I like the holding, and then something needs to clamp on the top of the lid and allow you to turn it.* (F-EnE-4)
- *What you need is something that can be stationary and grip the jar, while they twist the jar.* (M-GE-4)
- *So I need some way to either hold the bottom or top part still and then turn either the bottom or top*. (F-ME-4)
- *Just making something to hold the jar very effectively . . . like rubber that won't let the jar slip.* (M-EE-3)

This moment of insight was pivotal for the students, and they recognized it as such:

- *Alright, so I feel like I'm making . . . some progress. (M-ME-4)*
- *Okay, at least I have an idea . . . I think it'd be good. (M-ChE-2)*
- *Right now, I'm like, moving along here. (F-ME-4)*

When the students reached the point where they correctly interpreted the problem, their developmental path to a solution changed from one of ambiguity to one of clarity. While there were still concerns with actually building their prototype with limited materials, they recognized that they reached a major milestone leading to a more straightforward and efficient path to a viable solution.

It is also interesting to note that, from the students who correctly interpreted the problem, there did not appear to be a correlation between the time they correctly framed the problem and the total task time. As can be seen from Table 3, Total Task Time varied from 32 minutes to 69 minutes while correctly framing the problem varied from 10 minutes to 29 minutes. From the scatter plot (Figure 5), one can see that 5 students took between 62 - 69 minutes to complete the task but the time at which they correctly framed the problem varied considerably from 12 minutes to 29 minutes. Total task time was not a function of time of correct problem interpretation. When they correctly interpreted the problem was not as important as the fact that they did.

Participant Code	Engineering Discipline	Class Level (undergrad)	Time (min) at Interpretation	Total Task Time (min)
M-ChE-2	Chemical Engineering	2	29	66
M-EE-3	Electrical Engineering	3	10	32
M-GE-4	General Engineering	4	24	69
M-ME-3	Mechanical Engineering	3	19*	38
M-ME-4	Mechanical Engineering	4	12	62
F-EnE-4	Environmental Engineering	4	12	65
F-CE-4	Civil Engineering	4		72
F-ME-4	Mechanical Engineering	4	20	59

Table 3: Students interpretation time and task time *Incomplete/inaccurate interpretation

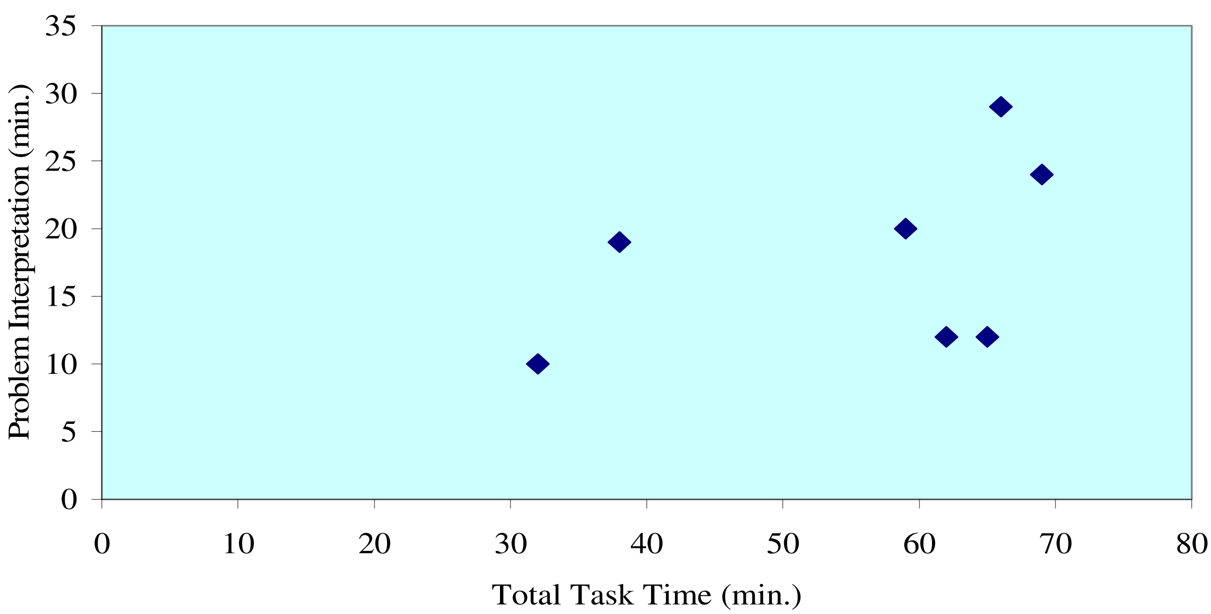

Figure 5. Problem Interpretation Time

Conclusions and Recommendations

Cross[6] argued that designers jumped to ideas for solutions before they fully interpreted the problem and that this is appropriate behavior for ill-defined problems. He wrote, "For designers, it is the evaluation of the solution that is important, not the analysis of the problem" (p.82). However, we found that for these eight student designers, the analysis or interpretation of the problem was critical. How students interpreted the problem not only dictated the design path, it influenced the solution as well. For these students, correctly interpreting the problem was crucial in designing an effective solution.

Some of our students did indeed jump to solutions quickly, sometimes as soon as the design task was read, even before gathering any information from the cards. As Cross[6] suggested, problem analysis is often hasty or absent. How can engineering design instructors encourage more thorough analyses of design problems? How can engineering students enhance skills in problem interpretation?

- One proposal is to develop a semi-formal academic program specifically addressing this often-absent step of problem interpretation. [30]
- It would behoove instructors of design courses to de-emphasize solutions and focus on a more thorough analyses of the problem until students are certain enough information has been gathered, and that nothing essential has been overlooked. Since one characteristic of creative thinking is to delay closure, [31] it follows that instructors similarly need to encourage students to delay formulating solutions to design problems in order to focus on problem interpretation. This strategy, to thoroughly analyze problems *without* proposing a solution, might be incorporated periodically throughout the course curriculum.
- As mentioned earlier, developing a creative solution is often a matter of problem restructuring by reorganizing existing knowledge, and that designers may intentionally restructure a problem to be ill-defined as a creative step in problem solving. [5-9] Instructors might encourage their students to look at *opposing* perspectives before beginning to formulate solutions. If a bridge washes out during the rainy season, what might happen to the bridge during a drought? When is having lots of water necessary/helpful/enjoyable? Exploring elements from these perspectives might prove useful in problem interpretation.
- Most students have had years of practice using algorithmic methods to reach one solution. To help students go beyond their comfortable "proven-fast-and-easy" linear way of problem solving, instructors might consider incorporating creative insight activities. There is an almost endless supply of exercises available, but a classic example requiring a shift in perception is Dunkers Candle Problem. [32] For this exercise, one is given a box a tacks, a candle, some matches, and a cork board. The problem is to attach a lighted candle to the upright board without dripping wax on the table. This seems a simple problem but many students struggle as they first try to attach the candle to the board by using the wax as some type of adhesive, or by using the tacks to catch the dripping wax. [33] To solve the problem, subjects need to change their perception of the box from something that holds tacks to an object that can be used as a platform.
- To encourage students to be comfortable with ambiguity and non-linear thinking, instructors might incorporate some improvisational exercises in class. These activities

have crossed the boundaries of theater and found their way into industry and corporate settings to enhance more creative thinking and problem solving. [34-37]

The basic strategies presented here are ideas offered to design instructors as suggestions in order to delay closure (delay proposing solutions) and to help students develop more diverse perspectives, in order to more fully analyze and correctly interpret design problems.

Understanding the engineering design process is important in order to understand and implement effective teaching of design courses**.** Pahl[1] noted a decade ago that good solutions come from a thorough analysis and clarification of the task. The results of this limited qualitative study indicate that correct analysis and interpretation of the problem may be a crucial component of the design process that deserves more attention in engineering education. We therefore suggest that engineering design instructors initially place more emphasis on problem interpretation rather than problem solutions.

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