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Don't Tell Me What You Know, Tell Me What You Would Actually Do! Comparing Two Design Learning Assessment Approaches

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Introduction

In comparing two streamlined methods to assess design knowledge, a method focused on critiquing an existing design process is shown to more closely match observed design behaviors than an open-ended prompt. This research paper describes the comparison of two engineering design knowledge assessment methods in terms of their ability to assess the procedural nature of design knowledge. In particular, the focus is on the methods’ ability to assess if students know to engage in problem formulation activities early in a design project. Problem formulation activities are not only key drivers of design, but prior work has shown that fewer than 20% of students entering engineering programs recognize the role of and engage in problem formulation[1].

Driving this research is viewing engineering design as a set of behaviors. As opposed to being declarative, factual knowledge, engineering design is about knowing *how* and *when* to do certain things (i.e., procedural knowledge). As such, the measurement of design knowledge needs to measure the procedural knowledge underlying effective design behaviors. Procedural assessment methods aimed at characterizing behaviors such as Verbal Protocol Analysis and ethnography of design teams, however, are prohibitively time intensive for engineering educators to use routinely in their classes. The focus here is on evaluating two less time-intensive, or “streamlined,” assessments with respect to their ability to capture procedural knowledge.

Taken together, the research question addressed in this study is: *Can streamlined declarative assessment techniques adequately capture procedural knowledge about problem formulation design activities?*

Prior Literature

Design knowledge is procedural in nature. While procedural knowledge is about knowing *how* to do something, declarative knowledge is knowing *that* something is[2]. If someone shows you how to make a peanut butter and jelly sandwich, they are expressing their procedural knowledge. If someone reads about the steps to make a peanut butter and jelly sandwich and then tells (or, “declares”) you what they just read, they are expressing their declarative knowledge.

Engineering design is, by nearly any definition, a process. People have called it

- a “social process”[3],
- a “systematic, intelligent process”[4],
- a decision process[5], and
- “the process of devising a system, component, or process to meet desired needs”[6].

In being a process, the desire in assessing engineering design knowledge is to assess the procedural knowledge of how someone designs as opposed to the declarative knowledge someone has memorized about design. The challenge is that directly measuring procedural knowledge requires someone showing you how they design. If they merely tell you how they design, on the other hand, then they *might be* expressing how they would actually design… but they may also just be expressing their declarative knowledge about design.

Connecting to Bloom's Taxonomy, declarative knowledge tends to be associating with "remembering" and "understanding" while procedural knowledge tends to be associated with higher levels such as "applying" and "creating." Assessment of knowledge at the application or creation level of Bloom's Taxonomy requires more than having someone declare that they remember that knowledge… it requires accessing someone's authentic design behaviors, not just their thoughts on design.

Direct procedural measurement approaches have been used to measure design.

Two methods for assessing engineering design knowledge – ethnography and Verbal Protocol Analysis (VPA) – explicitly focus on procedural knowledge (see [7] or [8] for reviews of a additional design knowledge assessment approaches). Both involve observing the behaviors of subjects as they design.

In *ethnography*, the researcher "embeds" themselves on a design project with the subjects and has both a participant and observer role. Ethnography has been used widely to assess design behaviors[3,9,10]. In the study conducted by Newstetter, for example, the researcher worked on an undergraduate design team for an entire term while taking copious notes and observations about her experiences and those of her student teammates. In addition to her participant observations, Newstetter conducted interviews with students in the class at various points during and after the term. The data is extremely rich – in Newstetter's case highlighting that "doing design does not ensure the learning of design." Clearly, however, the rich data came at a cost – the time required to perform such a study is unparalleled.

Videoing design teams as they work is another way to capture design behaviors. The most prominent method associated with videoing of design teams is Verbal Protocol Analysis (VPA), in which subjects "think aloud" as they design. The videos are transcribed, coded, and analyzed. Recording, transcribing, coding, and analyzing VPA studies is time intensive – perhaps ethnography is the only approach that takes more time. As with ethnography, though, the direct access the actual behaviors of a designer is the reason so many have used this approach (see, for example, Cross's *Analyzing Design Activity*[11] and the work of Atman and her collaborators at the University of Washington[12,13]).

Due to their ability to measure procedural knowledge, researchers studying engineering design knowledge rely heavily on ethnography and VPA. Design *educators*, however, would not gain enough value from performing such studies on students in their classes to warrant the intense amount of time required; educators need more efficient means to assess learning. Hence, the purpose of this study is to evaluate two streamlined approaches – each taking no more than 10 minutes of class time (for the whole class) and 1 minute of coding per response – with respect to their effectiveness in measuring procedural knowledge. While each approach aims to assess procedural knowledge, they both do so by asking students to declare their knowledge. This drives the research question of this study: Can streamlined declarative assessment techniques adequately capture procedural knowledge about problem formulation design activities?

Methods and Experimental Design

Two design knowledge measurement approaches are compared against actual behaviors exhibited by students during design. The two streamlined design assessment and the design project from which actual behaviors were observed are described in this section. The focus is on problem formulation design behaviors such as engaging stakeholders, performing research, identifying needs, and writing requirements.

One assessment method is an open-ended question where students describe how to design a product. Referred to as the "open-ended" method in this paper, this approach asks a student to describe (using words and/or drawings) how they would design a certain product, e.g., a new toothbrush from someone without use of their fingers or a device to fasten backpacks to a mountain bike. In some cases, such open-ended assessments just say "describe your design process," without any reference to a particular product or system (for example, such a prompt is one part of a larger study of assessment techniques in [14]).

The exact wording of the prompt used in this study is included in the appendix. Students were given 10 minutes during class to write their answers.

The open-ended method is process-focused (unlike design artifacts), at the individual level (unlike reports), and streamlined (unlike ethnography or video analysis). And, compared to the second method in this study, it does not appear to lead a student to respond in any particular way – it appears to be a neutral way to access a student's knowledge.

In this study, the responses of students were scored only for their inclusion of problem formulation activities. A student response that indicated that they would do research, talk to users, or generally "identify the problem" early in the design process received 1 point, while a response that did not indicate any such activities received 0 points.

The second method is the Design Process Knowledge (DPK) critique, an instrument previously used by multiple researchers in several studies to assess student recognition of the importance of specific design activities. The Design Process Knowledge (DPK) critique was designed to measure the types of activities and their relative arrangement over time that students think are important. Like the open-ended prompt, it is process-focused (unlike design artifacts), at the individual level (unlike reports), and streamlined (unlike ethnography or video analysis).

In the DPK, students are shown a Gantt chart of a proposed design process for a specific product and asked to critique the proposed process. The exact wording of the prompt used in this study is included in the appendix. Students were given 10 minutes during class to write their answers. The proposed design process used in this study does not include any problem formulation activities (See Figure 1).

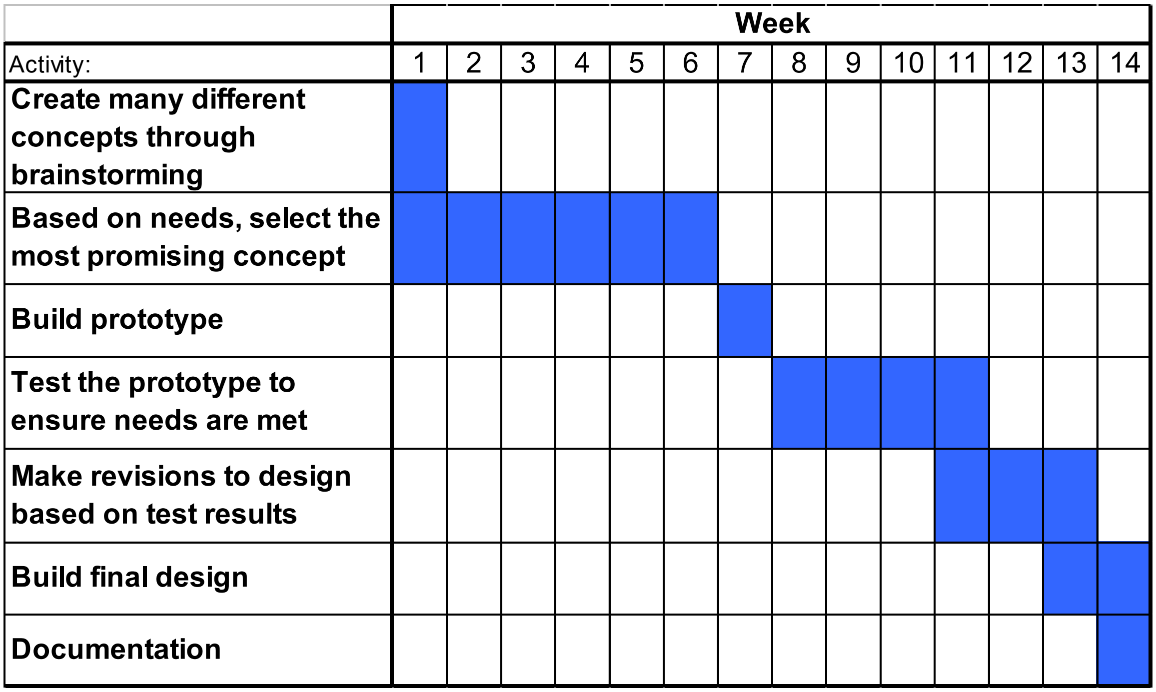

Figure 1 Proposed Design Process in Design Process Knowledge Critique

A rubric developed to evaluate answers rates answers on seven design traits. In this paper, though, the only evaluation is a binary assessment of one design activity: is the lack of problem formulation activities in Figure 1 identified or not.

The details of the DPK and the rubric are described in other papers[15-17]. Researchers have used the DPK on first year students[16-18], capstone students[15], experts[16,19], and elementary teachers[19].

The two streamlined methods are compared to actual behaviors observed as students complete a design project. Students were given a weeklong design project to complete in a team. The project focused on the problem of their professor needing to accommodate more students in his office during office hours. The exact wording of the prompt used in this study is included in the appendix.

Whether the team engaged in problem formulation activities was measured simply by observing the number of teams that came to his office to observe the environment for which they were designing (i.e., his office) or ask a key user (i.e., the professor) questions about his needs and wants. All other problem formulation activities (e.g., writing requirements) would stem from such observations and interviews – hence why going to the office was the measure.

Sample and Results

The sample consisted of 148 first-year engineering students at a public university in the mid-atlantic enrolled in a required first-year engineering course between 2012 and 2015. The two assessment methods were randomly assigned to students, resulting in half of the sample completing each assessment method. The assessments were given on the first day of class.

All of these 148 students were assigned the design project on the first day of class, too. They worked on self-formed teams, performing nearly all of the work outside of class. Between 2012 and 2015, a total of 25 teams completed the design activity.

Based on four years of data, the open-ended method overestimates the number of students who actually demonstrate problem formulation behaviors during a design project. Results from the DPK align more closely with observed behaviors during a design project. Only 16% of teams actually went to the professor's office during the project in which they designed a new way to accommodate more students in his office (further, none of the teams conducted any outside research on chairs of office layouts for the project). More than 4x this percent of students (69%) indicated problem formulation activities (e.g., observing or talking with users, doing research) on the open-ended assessment. Twenty-two percent of students identified problem formulation activities as missing in the DPK. These results are shown in Table 1.

Table 1 Percentage of Students Who Correctly Identified that Problem Formulation Activities Using Each Assessment Method

	# knowing to perform Problem Formulation activities	Sample size	%	Fischer's exact test p-value when compared to "Observed in design activity" 16%
Open-ended method	51	74	69%	<0.001
DPK	16	74	22%	0.774
Observed in design activity	4	25	16%	--

Fischer's exact test revealed that the difference between the percent recognizing including problem formulation activities in the open-ended assessment (69%, n=74) and the percent actually performing problem formulation activities in the design activity (16%, n=25) is statistically significant at P<0.001. For the open-ended p-value to go above 0.05, we would have needed to observe 12 teams (3x the actual value!) coming to the professor's office during their project. There is no statistically significant difference between the percent recognizing the lack of problem formulation activities in the DPK (22%, n=74) and the percent actually performing problem formulation activities in the design activity (16%, n=25).

Discussion

While design is inherently procedural in nature, the DPK declarative assessment approach produces similar results to observing actual problem formulation design behaviors. The main upside to an approach like the DPK is that it requires far less time than observation-based assessments like VPA and ethnography. While the DPK will not gather the full richness of the data as either VPA or ethnography, it could be a useful tool for engineering design educators to use to measure learning in their classes. One of the key assets of the DPK is revealed when comparing it to the open-ended assessment.

The open-ended assessment demonstrated that students that tell you the right answer would not necessarily show you the right behavior. The much higher scoring on the open-ended response implies that students are aware that problem formulation is important; whereas the much lower scoring on both the DPK and actual observations indicate that student do not act on that knowledge. It appears that the knowledge of the importance of problem formulation activities is only declarative stored as a fact for many students. Using keywords from Bloom's Taxonomy, while many "remember" that problem formulation is important, most do not "apply" that knowledge when they design. An actual response to the open-ended prompt such as the one in Figure 2 gives some insights as to why this might be the case.

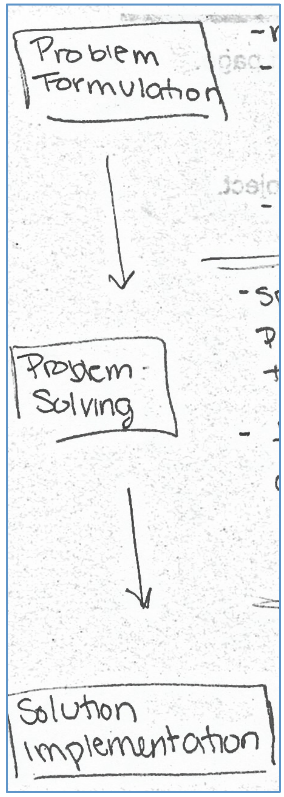

Figure 2 Actual Response to Open-Ended Response

The words "Problem Formulation," "Problem Solving," and "Solution Implementation" seen in Figure 2 are the *exact words* from the textbook used in the class. The students had not been assigned to read anything from the book prior to the assessment, but several students must have read ahead … and then put the exact wording in their response. Such textbook regurgitation of knowledge is representative of the "remembering" level of Bloom's Taxonomy… of declarative knowledge. Such exhibitions of declarative knowledge were fairly common among the open-ended response and rare among the DPK. **A likely reason why the DPK outperforms the open-ended method when compared to actual observed behaviors is that the open-ended method elicits declarative knowledge while the DPK is able to access procedural knowledge.**

It seems that a completely open-ended question implicitly prompts students to tap into their declarative knowledge. Critiquing the proposed process in the DPK gets students to think more about what they might actually do, not just what they would say. We should note that problem formulation activities were NOT present in the proposed process of the DPK critique. In providing their critique, students needed to identify that problem formulation was missing. While not proven with the data in this study, the results probably would have been very different if the proposed process included adequate problem formulation activities: it is much easier to say "those steps are good steps" than it is to realize something is missing.

Further Work and Limitations

Limitations include that individual responses are being compared to team behavior and the associated inability to pair responses. The responses to both the open-ended and DPK assessments were completed by individuals while the design activity was completed by teams. This creates several limitations, notably that an individual's behavior is not the same as the team's behavior (e.g., a team may engage in problem formulation activities due to the actions of just one individual). Additionally, the comparisons between assessments cannot be paired; therefore, we cannot evaluate if the same individual that indicated that problem formulation is important in the DPK or open-ended assessment exhibited any problem formulation behaviors in the design activity. We can only use population-level statistics.

To further identify the cause of the improved learning, next steps include interviews with students. Interviews will be used to discuss discrepancies between observed behaviors and written responses. In particular, we will focus on students who wrote that they would incorporate problem formulation activities that ultimately did not exhibit such behaviors during the design activity.

Conclusion

While design knowledge is procedural in nature, purely procedural assessment techniques focused on directly observing behaviors are too time intensive for engineering educators to regularly use with students. In this study, two streamlined assessment approaches were studied to determine if the results from either matched results from observing students during a design project. In the context of problem formulation behaviors, the Design Process Knowledge critique showed similar results to observations of students during the design project while the open-ended assessment overestimated engineering design knowledge. The primary explanation for why students included problem formulation activities in the open-ended assessment when they did not perform such behaviors is that the open-ended assessment elicits recall of facts (i.e., declarative knowledge) moreso than authentic behavior (i.e., procedural knowledge).

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Appendix

Open-ended Assessment

F15-wk1

The purpose of this *is for us to better understand what students learn in ENGR 1620.*

DO spend the full 10 minutes on your response

Your job is
to create a design process for a specific project.

Print Your Name Here

Print Your Instructor's Name Here

Page 1

F15-wk1

Injuries due to poor posture in office chairs is a growing problem. A major chair manufacturer has come to you to design a system to sense a person's posture, store that information, and display it.

Make a flowchart of the design process you would use for such a system. What steps would you plan to go through?

Page 2

DPK Critique Assessment

The purpose of this *is for us to better understand what students learn in ENGR 1620.*

DO spend the full 10 minutes on your response

There is a chart of a design process on the next page.

Your job is
to critique the design process represented by the chart.
Identify the good and bad things about the process.

Print Your Name Here

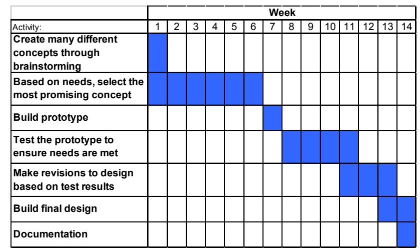
Print Your Instructor's Name Here

Page 1

Injuries due to poor posture in office chairs is a growing problem.
A major chair manufacturer has come to you to design a system
to sense a person's posture, store that information, and display it.

Shown below is a proposed design process for you to follow.

No work was done prior to what is shown in the chart.



Critique this process on the next page.

Page 2

What is good about the proposed process?
BE SPECIFIC! EXPLAIN *WHY* SOMETHING IS GOOD!

What should be changed about the proposed process?
BE SPECIFIC! EXPLAIN *WHY* SOMETHING IS BAD!

Page 3

Weeklong Design Activity

Chair of Scrap

Learning Objectives:	learn about design and teaming through both doing and reflecting get practice presenting in front of class
Due:	[Enter Due Date]
Format:	To be completed by teams of 5-7 students

I don't have enough seating in my office for students.

And I want you to design something to help me. I want to be able to have seating for 4-5 students total. I want something that is durable, looks good, and can be out of the way when I don't have such a large group of students to meet with. I'd like a solution that is adaptable to my needs as they might change over the next few years. A rough layout of my office is shown below.

For materials, you can only use items that can be recycled curbside by the City of Charlottesville. In addition, you can use tape or other bonding agents if needed, but I am not interested in seeing a chair that looks like a giant piece of duct tape.

In class:
Today, you will spend time forming teams and getting started on this project.

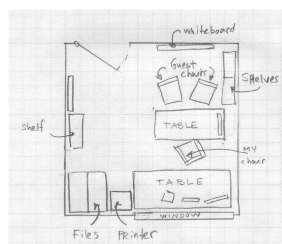
Advice
Be smart with your time – don't sink tons of hours into something that can be done more simply – split up work among the team when possible. This assignment could take forever if you let it…

Presentation - team
Each team will have 4 minutes to present their design to the client (me!). You should use Powerpoint and the projector for your presentation. Due to the 4 minute time limit, no more than 4 slides should be used per team. Each group needs to develop a team name – and make your team name clear during the presentation – as well as the names of each of your team members (put your names on the title slide).

Design Process – Individual – work on this alone
Each individual is to describe, on one page, the *process* that their team used to design a solution (i.e,. what did you do first, second, …). Your description must be a graphical (as in, visual) representation of the process. On this page, point out 1-2 things that you think are good things about your team's design process and 1-2 things you think could have been done better.

To Turn In:

- Powerpoint presentation: one student on each team uploads it to Collab by 9:00 am on due date; use the file naming convention listed in the class policies.
- Your chair: One per team… bring it to class on the due date. It should be a "working prototype", meaning that I can use it during class/could put it in my office.
- Design Process: each individual brings a hard copy to class on the due date



Rough Office Layout