Work In Progress: Assessing Students' Changing Conceptions of Design

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WIP: Assessing Middle School Students' Changing Conceptions of Design

Abstract
Design is a complex, ambiguous, and iterative process. Expert designers place extra emphasis on particular design activities, such as framing problems, practicing idea fluency and reflecting on their design process. Understanding students' prioritization and re-prioritization on design strategies after undertaking a design project allows an opportunity to see how students' conceptions of design develop. This work-in-progress uses a conceptions of design research instrument adapted to be sensitive to students' design experience with a simulated engineering design environment (Energy3D). Students select the five most important and five least important design activities from a list of twenty and provide an open-response regarding one of their selected terms for both most and least important terms. The survey was administered as a pre- and post-test assessment in three middle schools in the Midwest with over 700 students. Through statistical analysis of changing terms of McNemar tests and through qualitatively analyzing the open responses, we are working towards validating this tool for use in middle schools across the US. This tool requires little time from students to complete, and is relatively straightforward for educators to assess meaning it could be an effective and efficient design assessment tool.

Keywords: engineering design, design knowledge, assessment, design conception

Introduction

Design is a complex cognitive process[1] and at the P-12 level is often recognized as a pedagogical tool for teaching science, with design providing the context and serving as a vehicle to learn science. These pedagogical approaches have been successful in student learning of science[2,3,4,5]. Because this approach emphasizes science learning, the opportunity to foster design learning is often lost. Offering a way to understand and assess student learning of design would provide utility for educators. However, traditional methods of assessing students design cognition such as verbal protocol analysis are time-consuming. Offering a less resource-intensive approach to understanding students' design thinking could be of great value.

In our approach to understanding students' conceptions of design, we have drawn from the design behaviors of informed versus beginning designers[6]. From this work, we know that informed designers engage in design activities such as problem framing, practicing idea fluency and reflecting on their design process, as compared to prematurely trying to solve problems or go with the first solution that comes to mind. Our goal is to understand how students' conceptions of design develop over the course of a design project. We have modified a Conceptions of Design Instrument[7] that encompasses a broad range of design activities to be sensitive to students' design experience with a simulated engineering design environment (Energy3D). We hypothesize, based on previous research[8,9,10] that students' post-test responses would show a change towards more informed design behaviors.

Research Questions

This research seeks to understand:
RQ1: What design activities became MORE important to students after a design project?
RQ2: What design activities because LESS important to students after a design project?

RQ3: After a design project, how FAMILIAR were the presented activities to the students?

Research Methods

Research Participants & Classroom Context

This study was conducted at three middle schools (ages 12-14) in the Midwest, United States. Students participated in an in-class design project using Energy3D (http://energy.concord.org/energy3d/), a CAD simulation environment. Energy3D is developed by the Concord Consortium as "a computer-aided engineering tool for designing, analyzing, and constructing green buildings and power stations that utilize renewable energy"[11]. The user-friendly software works in a way that allows students to see the effects of each design and specifications they choose to their overall design specifics. It offers a simple 3D graphical user interface for drawing buildings, and evaluating their performance using cost and energy (solar and heat) simulations (see Figure 1).

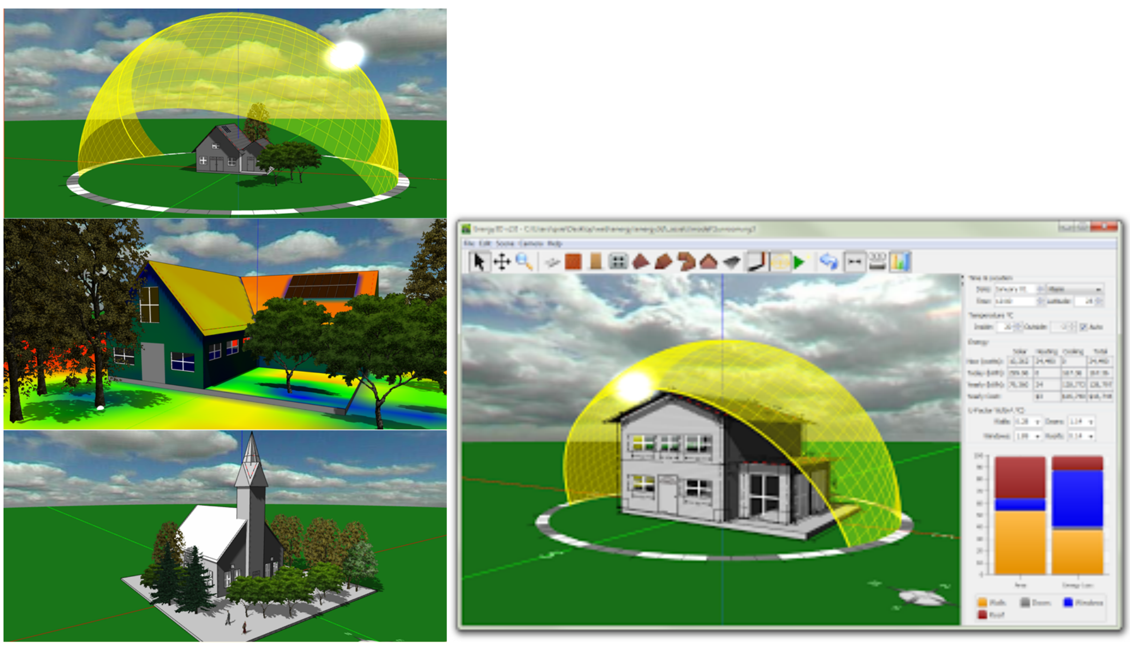

Figure 1. (Left) Energy3D solar simulator, heat maps, and example building. (Right) Energy3D performance calculations (e.g., energy, cost).

Design projects at all three schools involved using Energy 3D to design single-family homes that attempted to balance energy consumption, construction cost, livability, and aesthetics, but the three schools differed significantly in the scale of their implementation. One 8th grade in an urban setting allocated two weeks to design three unique solutions for almost 100 students. One of the two 7th grades in a suburban setting provided a similar design task and timeline, but was used in all 7th grade science classrooms for almost 300 students. The third classroom, a 7th grade science class in a suburban setting was a fully integrated design project in both math and science classrooms, with a community stakeholder, and 4 four weeks of design time with scientific inquiry labs outside of Energy3D. The demographics of the schools represent a large variety of students as the suburban schools are very resource rich and the urban school is resource poor. Relationships with these school partners were developed over years and allowed for full partnership between researchers and educators.

Conceptions of Design Test

An electronic survey was administered as a pre- and post-test assessment with 748 students fully completing both the pre- and post-tests. A Conceptions of Design Test (CDT) was used to characterize changes in learners' prioritization and understanding of 20 design activities from "analyzing data" to "using creativity" (see Table 1). The instrument included three sets of questions: (a) given the list in Table 1 (in alphabetical order to reduce response bias) "select the five most important and five least important concepts for producing a high quality design", and (b) "for one of the five terms you marked as most important for producing a high quality, please explain why you believe it is important." (c) "for one of the five terms you marked as least important for producing a high quality, please explain why you believe it is not important."

Table 1. Conceptions of Design Instrument

List of Design Activities			**Instructions**
Analyzing data	**Gathering information**	**Modeling**	*Selection*: Which **5** would you consider the MOST/LEAST important in terms of producing a high quality design? *Open-ended response*: For one of the most/least important terms selected, please explain why
Balancing benefits & trade-offs	**Generating alternatives**	**Planning**	
		Prototyping	
Brainstorming	**Identifying constraints**	**Reflecting**	
Building	**Iterating**	**Setting goals**	
Communicating		**Sketching**	
Conducting tests	**Making decisions**	**Understanding the problem**	
Evaluating		**Using creativity**	

Prior to ranking the importance of these activities, students were asked to review the list of design activities and respond with their familiarity with each term. The familiarity scale included: (a) I am VERY familiar with this term, (b) I am SOMEWHAT familiar with this term, and (c) I am NOT familiar with this term.

Data Sources

Data analyzed includes:

(1) All 748 pre- and post-test responses to the CDT "Which 5 would you consider the MOST important in terms of producing a high quality design?"
(2) All 748 pre- and post-test responses to the CDT "Which 5 would you consider the LEAST important in terms of producing a high quality design?"
(3) All 748 post-test responses to "Please review the following design activities and answer your familiarity with each term."

Data Analysis

A statistical analysis of changing terms was conducted by performing the McNemar test for:

(1) Pre- to post-test responses to the CDT "Which 5 would you consider the MOST important in terms of producing a high quality design?" for each of the 20 design terms
(2) Pre- to post-test responses to the CDT "Which 5 would you consider the Least important in terms of producing a high quality design?" for each of the 20 design terms

Additionally, a third analysis was performed by totaling the number of times students stated they were "NOT familiar" with the design activity phrases.

Results & Discussion
Analysis of student responses to the Conceptions of Design Test resulted in three findings:

Finding #1: Students' changing perception of the following terms of "MOST important to design" significantly changed after the design project: Balancing Benefits & Trade-offs, Brainstorming, Communication, Conducting Tests, Gathering Information, Identifying Constraints, Prototyping, Sketching and Understanding the Problem (as shown in Table 2).

An exact McNemar's test determined that there was a statistically significant difference in the proportion of students that selected the terms listed in Table 2 from pre- to post-test.

Table 2. *"Most Important" terms' change from pre to post*

Design Activities	Shift in Importance	Pre (N)	Post (N)	*p* Sig.
Balancing Benefits & Tradeoffs	Less	196	41	*<.001****
Brainstorming	Less	271	236	*.047**
Communicating	Less	260	225	*.040**
Conducting Tests	More	207	256	*.003***
Gathering Information	Less	269	233	*.048**
Identifying Constraints	More	93	127	*.010**
Prototyping	Less	155	108	*.001***
Sketching	Less	100	57	*<.001****
Understanding the Problem	More	361	402	*.031**

*$p<.05$. **$p<.01$, ***$p<.001$

Finding #2: Students' perception of the following activities for "LEAST important to design" significantly changed after the design project: Analyzing data, Balancing Benefits & Trade-offs, Communication, Conducting Tests, Evaluating, Identifying Constraints, Prototyping, Sketching, and Using Creativity (as shown in Table 3).

An exact McNemar's test determined that there was a statistically significant difference in the proportion of students that selected the terms listed in Table 3 from pre- to post-test.

Table 3. *"Least Important" terms' change from pre to post*

Design Activities	Shift in Importance	Pre (N)	Post (N)	Sig.
Analyzing Data	Less	109	70	*.002***
Balancing Benefits & Tradeoffs	Less	391	341	*.008**

Communicating	More	134	165	*.041**
Conducting Tests	Less	125	79	*.001***
Evaluating	Less	168	137	*.049**
Identifying Constraints	Less	223	193	*.020**
Prototyping	More	216	252	*.036**
Sketching	More	330	411	*.000***
Using Creativity	More	210	258	*.005**

**p<.05. **p<.01, ***p<.001*

Finding #3: After a design project, students expressed less familiarity with the following design activities: Balancing Benefits & Trade-off, Identifying Constraints, and Iterating

Figure 2 illustrates the frequency with which students responded they were NOT familiar with the three least important activities. As noted in Figure 2, students identified the activities Balancing Benefits & Tradeoffs as NOT familiar a total of 214 times on the post-test, Identifying Constraints as total of 93 times, and Iterating a total of 259 times.

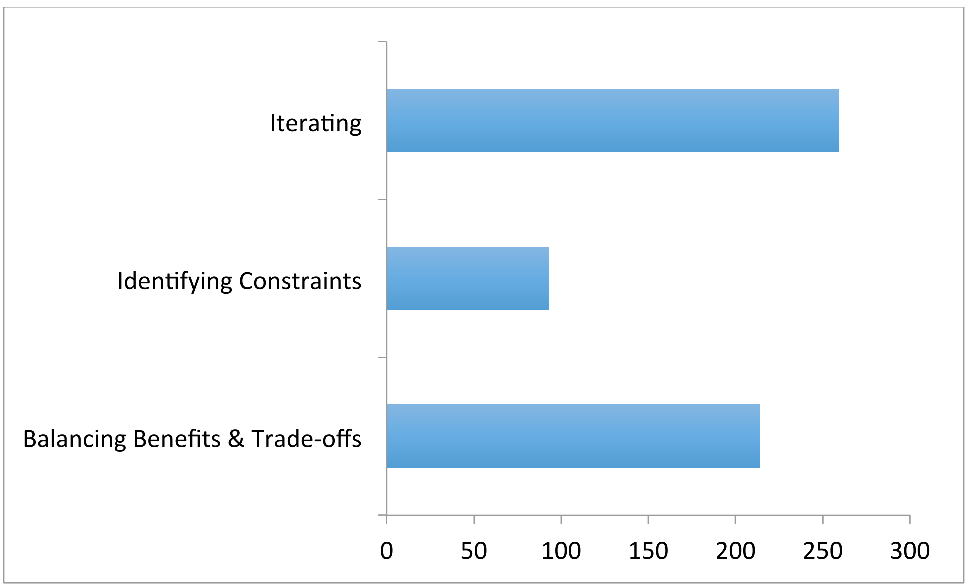

Figure 2. Number of students reporting being unfamiliar with an activity, post-test (N=748)

These findings bear similarities and differences to other studies in different contexts. For example, the middle school students in our study found 'communicating' to be less important after partaking in a design project. Although Mosberg et al.'s[12] think aloud study investigated conceptions of design, there are two main differences between our current study and their research. First, Mosberg et al.'s[12] study focused on experienced engineers rather than student engineers. Second, Mosberg et al.'s[12] study looked at conceptions of design prioritization in general, (not changing conceptions after a design project), as these engineers already had significant design experience. Interestingly, the experienced engineers found 'communicating' to be a most important design activity although our results with middle school students found the opposite. The students in our study found 'communicating' to be less of a "most important" design activity after a design project and more of a "least important" design activity after the same design project. This could be explained due to the context of the students' design project. They did not have to communicate with teammates, as this was an individual activity, nor did they have to communicate results to stakeholders. Communication as teamwork and with stakeholders could have much longer implications for working engineers. Adams et al looked at changing conceptions for first year engineering students after they took part in a design activity. First year engineering students exhibited similar prioritization as the middle school students in that communication became less important to them, showing students' conceptions can differ quite a bit from professionals' conceptions due to scale and context.

In addition, 'trade-offs' was more important to the professionals in Mosberg et al.'s[12] study and to the first year engineering students in Adams & Fralicks'[7] study became more important to the first year engineers. As discussed in Figure 2, the middle school students were not very familiar with the language of 'making tradeoffs' and this lack of language could contribute to the conception discrepancy. Professionals and college students would likely be more familiar with this concept in design and elsewhere.

Similar to Mosberg et al.'s[12] results, our study showed 'understanding the problem' and 'identifying constraints' to be important design concepts and 'prototyping' and 'sketching' to be less important design activities. 'Conducting tests' became a more important concept for both sets of students.

Conclusions & Future Work

Preliminary work indicates that students identify changing priorities in the usefulness of design strategies after completing a design project, although findings in a middle school context share both similarities and differences with previous work conducted with beginning engineering students and practicing engineers. Our analysis also suggests that certain terminology such as 'balancing benefits & tradeoffs' and 'iterating' are not familiar to middle school students and could pose difficulties in assessing students' conceptions of these important activities. Iterations of this test will explore revisions in terminology for unfamiliar concepts. Through this ongoing work, we seek to answer to what extent middle school students understand and interpret design terms.

Future work will investigate to what extent students' results from this Conceptions of Design Test reflect their design behaviors as collected from log data of their design process. This will allow us to understand if students do what they say is important in design. We plan to triangulate our findings with additional sources of data such as student interviews and design artifacts to better understand how well the Conceptions of Design Test (CDT) assesses design conceptions of students. Because this tool requires little time from students to complete, and is relatively straightforward for educators to assess it could be an effective and efficient design assessment tool.

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References

[1] V. Goel, & P. Pirolli. "The structure of design problem spaces." *Cog. Sci.* Vol. 16, No. [1], pp. 395-429, 1992.

[2] X. S. Apedoe, et al. "Bringing engineering design into high school science classrooms: The heating/cooling unit." *J. Sci. Ed. and Tech.* Vol. 17, No. 5, pp. 454-465, 2008.

[3] D. Fortus, , et al. "Design-based science and student learning." *J Res in Sci Teaching* Vol. 41, No. 10, pp. 1081-110, 2004.

[4] G. N. Svarovsky, & D. W. Shaffer. "Soda Constructing knowledge through exploratoids." *J. of Res. in Sci. Teaching* Vol. 44, No. 1, pp. 133-153, 20017.

[5] K.B. Wendell, and H. Lee. "Elementary students' learning of materials science practices through instruction based on engineering design tasks." *J. of Sci. Ed. and Tech.* Vol. 19, No. 6 pp. 580-601, 2010.

[6] D. P. Crismond, David & R. S. Adams. "The informed design teaching and learning matrix." *J Eng. Ed* Vol. 101, No. 4, pp. 738-797, 2012.

[7] R. S. Adams, & B. Fralick, "Work in progress: A conceptions of design instrument as an assessment tool." Proceedings of the Frontiers in Education Conference, Washington, 2010.

[8] C. J. Atman, D. E. Kilgore, & A. McKenna, "Characterizing design learning: A mixed-methods study of engineering designers' use of language." *J. Eng. Ed*., Vol. 73, No. 3, July, pp. 309-326, July, 2008.

[9] N. Cross "Design cognition: Results from protocol and other empirical studies of design activity.," In C. M. Eastman, W. M. McCracken, & W. Newstetter (Eds.), Design Learning and Knowing: Cognition in Design Education (pp. 297-314). New York: Elsevier, 2001.

[10] M. E. Cardella, C. J. Atman, J. Turns, and R. S. Adams, R. S. "Students with Differing Design Processes as Freshmen: Case Studies on Change." *Int. J. Eng. Ed*., vol. 24, no. 2, p. 246, 2008.

[11] S. Nourian, and C. Xie. Energy3D [Software]. Available from http://energy.concord.org/energy3d/index.html, 2016.

[12] S. Mosberg, R. S. Adams, R. Kim, C. J. Atman, J. Turns & M. Cardella (2005). "Conceptions of the engineering design process: An expert study of advanced practicing professionals," *ASEE Conference Proceedings*, Portland, June, 2005.