Student Conceptions of 'Conducting Tests' in Design in the Middle School Classroom

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***Abstract*—Engineering design is a complex experience for students to undertake and for instructors to assess. Conducting tests is a critical design practice, yet the research on K-12 students' conceptions on conducting experiments is limited. Such research is essential as we attempt to understand how students become informed designers and ways in which we can support their transformation. By analyzing students' prioritization and re-prioritization of design strategies after participating in a design activity, this study examined how students' conceptions of design activities change over time. The study took place in three middle schools with 746 students. The main data source was the "conceptions of design test," which students completed a pre- and post-test, before and after completing a design project. We performed McNemar tests to quantitatively analyze students' changing conceptions of design. Results suggest that after a design activity, "conducting tests" became a statistically more important concept to students. Future work will investigate student rationale for this increased importance placed on "conducting tests" in design.**

Keywords—engineering design; conducting tests; experimentation; assessment

I. Introduction

Design is a process of learning [1, 2, 3]. An important part of becoming a designer is learning the language of design. Though the body of literature on design is extensive, the issues related to design learning in pre-college classrooms is an emerging topic of research. While the Next Generation Science Standards [6] highlight the importance of engineering practices along with science practices, assessing design practices is a complex task because design is such a complex cognitive activity. Design cognition research is not well developed at the K-12 level, but rather is more established within professional and college contexts [7, 8, 9, 10]. NGSS outlines performance objectives along with a list of evidence statements for assessment [6]. However, assessing these performance exceptions requires a research base grounded in understanding student cognition. Hence, in this study we expand expert design *research* to examine design learning among middle school students, particularly around the design strategy of conducting tests. A better understanding of students' use, conceptualization, and prioritization of conducting tests in a design context could help educators in guiding students to more informed and beneficial design practices.

This paper addresses the need for understanding student conceptions of "conducting tests." Through the context of a design project directed towards a net-zero energy home, students take a pre and post-test assessment to describe their conceptions of design terms. We quantitatively analyze responses on the assessment, describe preliminary results, and identify future work.

II. Literature Review & Conceptual Framewoek

Crismond and Adams' *Informed Design Teaching and Learning Matrix* [11], developed as a meta-literature review, contains nine engineering design strategies. The Matrix contrasts how these strategies are employed differently by informed designers as compared to beginning designers. The Matrix acts as an integrated framework that aims to facilitate design teaching, as well as improve design competence and practice in students to better support informed teaching with engineering design activities.

The sixth design strategy discussed in the Matrix is conducting experiments. It is an important strategy as designers run valid experiments to study the prototypes in order to optimize their performance. Informed designers conduct "fair tests" and experiments to learn about the design materials, the key variables and the system. Beginning designers, however, tend to run confounded tests by changing multiple variables at the same time. This results in ambiguous results and data analysis that would interfere with the product optimization. It is thus crucial for researchers and educators to understand students' conception and prioritization of conducting tests while doing design project to support their growth into becoming more informed designers.

The Next Generation Science Standards [6], highlights that carrying out investigations is a practice used in both science and engineering. In this study, students conducted tests and analyzed the results with a performance goal of creating an energy efficient house.

III. Research Questions

This research addresses students' use and prioritization of the term "conducting tests" in design through the following research question: How do students' *prioritization* of "conducting tests" change after introduction of a design activity?

IV. Research Methods

A. Participants & Classroom Context

This study took place in three separate middle schools (ages 12-14) in the Midwest, United States as 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" [14]. This user-friendly software offers a simple 3D graphical user interface for drawing buildings, and evaluating their performance using cost and energy (solar and heat) simulations (see Figures 1 and 2).

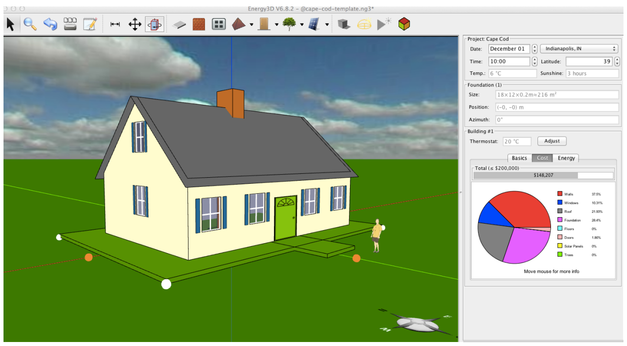

Fig. 1. (Example student design within Energy3D

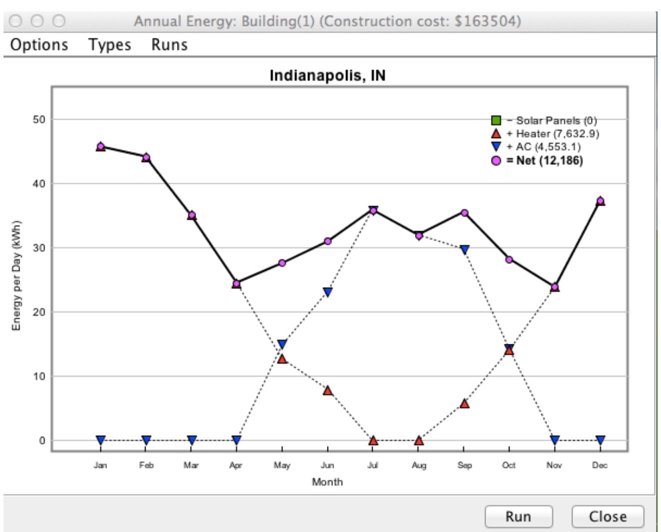

Fig. 2. Example energy analysis in Energy3D

B. Design Challenge

Students at all three schools (N=746) used Energy3D to design single family homes that consumed as little energy over the course of a year as possible while being cost effective, and also being attractive/comfortable. One 8th grade class in an urban setting allocated two weeks to design three unique solutions for 64 students. Three 7th grade teachers in a suburban setting used the same design task and timeline, with 367 students. The third school was 7th grade class in a suburban setting with 315 students was a fully integrated design project in both math and science classrooms, with a community stakeholder, and spent four weeks of design time with labs targeting specific science concepts outside of their time in Energy3D. The diverse demographics of the schools representing both resource-rich suburban schools and urban schools supports generalizability of results for different school settings.

C. Conceptions of Design Test (CDT)

A Conceptions of Design Test (CDT), developed by the authors, was used to characterize changes in learners' prioritization and understanding of 20 design activities from "analyzing data" to "using creativity" (see Figure 2). The CDT was adapted from an instrument designed by Mosberg, et al., [15] to understand practicing designers' design language. Later revisions of the tool focused on college designers' conceptions of design [16, 8, 17]. The instrument in this current study of middle school students included three sets of questions: (a) Given the list in Figure 2 (in alphabetical order to reduce response bias) "Select the five most important and five leave 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."

CONCEPTIONS OF DESIGN TEST

1. Which FIVE would you consider as the MOST important in terms of producing a high quality design? Circle your choices.
2. For one of the five you marked as most important for producing a high quality design, please explain why you believe it is important.
3. Which FIVE would you consider the LEAST important in terms of producing a high quality design? Circle your choices.
4. For one of the five you marked as LEAST important for producing a high quality design, please explain why you believe it is important.

1. Analyzing data
2. Brainstorming
3. Building
4. Communicating
5. Conducting tests
6. Evaluating
7. Gathering information
8. Generating alternatives
9. Identifying constraints
10. Iterating
11. Making decisions
12. Making trade-offs
13. Modeling
14. Planning
15. Prototyping
16. Reflecting
17. Setting goals
18. Sketching
19. Understanding the problem
20. Using creativity

Fig. 3. Conceptions of Design Test

Students completed the CDT through an electronic survey as a pre- and post-test, before and at the conclusion of their design challenge.

D. Data Sources

While the main data source was the CDT, the analysis targeted student answers to four response patterns:

(1) students who selected "conducting tests" as one of the MOST important terms for a quality design PRE-test

(2) students who selected "conducting tests" as one of the LEAST important terms for a quality design PRE-test

(3) students who selected "conducting tests" as one of the MOST important terms for a quality design POST-test

(4) students who selected "conducting tests" as one of the LEAST important terms for a quality design POST-test

E. Data Analysis

McNemar's tests were performed to determine whether the conducting test activity importance proportions increased from pre to post test. The test is appropriate for paired dichotomous categorical data in which the *p*-value of the test would report if there were a significant difference between the two proportions [18], allowing for statistical measure of changes in prioritization of conducting tests.

V. Results and Discussion

The McNemar test showed that there was a statistically significant difference in the proportion of students who selected "conducting tests" from pre- to post-test. These differences were evident in questions for most important and least important (See Table 3). In the case of students' selecting "conducting tests" as a least important term, a McNemar test showed that significantly fewer students considered it to be an unimportant term (χ^2 = .573, DF = 1, p = 0.000). Moreover, significantly more students found "conducting tests" to be a most important term from pre- to post-test (χ^2 = 29.051, DF = 1, p = 0.003).

TABLE I. "Conducting Tests" change in Priority from Pre to Post-Test

	Students' Shift in Importance (more or less)	**Pre Test N (%)**	**Post Test N (%)**	***p*-value**
Most Important	More	216 (29%)	266 (36%)	0.003*
Least Important	More	120 (16%)	73 (9%)	<0.001**

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

Altogether, the statistical results suggest that "conducting tests" became a more important concept to students after the design activity. In reviewing students' responses to the open-ended questions "For one of the five terms you marked as most/least important for producing a high quality, please explain why you believe it is/is not important" when students described "conducting tests," students also described "conducting tests" as important in a higher frequency on the post-test.

TABLE II. Student Open-Ended Responses to Conducting Test Frequencies

Test	***IS Important***	***IS NOT Important***
Pre-	31	13
Post-	52	4

Examples of how students described "conducting tests" on the post-test, start showing promise of students discussing the design activity in ways more consistent with informed designers:

> *"I believe that conducting tests is one of the most important design activities because it allows people to see what affects what. Conducting tests lets people know what changes they have made are efficient "*

> *"Conducting test is important because you figure out what your houses energy is and based off of the test you can make your house use less energy and make it better"*

VI. Conclusions & Future Work

This study suggests that after taking part in a design project, students learned to prioritize "conducting tests" as an important strategy in creating a high quality design solution. Future work will investigate to what extent students' prioritization of "conducting tests" on this Conceptions of Design Test reflects 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 in areas including and beyond conducting tests. 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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