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High School Students' Ability to Balance Benefits & Tradeoffs while Engineering Green Buildings

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High School Students' Ability to Balance Benefits & Tradeoffs while Engineering Green Buildings (Fundamental)

Abstract

The ability to balance benefits and tradeoffs is central to engineering and linked to promoting science learning. In this study we investigated high school students' explanations as they developed design solutions. We specifically examined explanations such as referring to data, connecting to scientific concepts and explicitly mentioning balancing benefits and tradeoffs. Data on student design processes and solutions were collected as students engaged in a project requiring the design of three unique passive solar houses using a computer-aided design software, Energy3D, with built-in energy simulation capabilities. Students developed three alternative solutions and determined which of their three designs they believed best met the criteria and constraints set by the design challenge. The main data sources included files of student designs with embedded analysis and electronic notes taken by the students. The presence of explanatory behaviors was used to evaluate alignment of students' decisions in selecting an idea for further design and testing. Data from 44 high school students and 132 design solutions were analyzed. Results show that students became increasingly more reflective with each subsequent design. In addition, students were more likely to cite data in their reflective explanations. Implications from these results are discussed as they pertain to educational suggestions.

Keywords: engineering design, high school, tradeoffs, experimentation, computer-aided design.

Introduction

Our understanding of what K-12 students learn from engineering design is limited. A 2008 literature review concluded that many K-12 engineering education projects lacked data collection and analysis to provide reliable evidence of learning.[1] Design is a complex cognitive process[2,3] and in the context of K-12 science education, engineering design is a complex cognitive activity in which students *learn* and *apply* science concepts to solve open-ended problems with constraints to meet specified criteria.

The complexity, open-endedness, and length of an engineering design process create unique opportunities for students to make science connections. The focus of engineering design assessment is not simply on whether or not students "get the right answer," but on how they acquire science and engineering knowledge and skills in the quest for optimal design solutions. Research claims[1] weighing evidence and assessing alternatives are essential to constructing scientific arguments. In that light, Next Generation Science Standards[4] (NGSS) requires arguing from evidence as well as obtaining, evaluating, and communicating information. In engineering design projects, students may learn more from failed designs than from successful ones because failure promotes the need to explain and revise. When students actively think through issues and develop their own arguments, they develop a better familiarity and understanding of science concepts.[5] Therefore, argumentation within engineering design provides a great opportunity for students to develop scientific thinking. The research presented in this paper provides an exploratory look at an engineering design activity set in a high school. Student reflections are used to examine student explanatory behaviors in designing. This exploratory analysis results in two main findings regarding the patterns of these explanatory behaviors.

Research Questions

What type of explanations do high school students develop as they engage in engineering design? Do these explanations change over time?

Research Methods

Research Participants & Classroom Context

This study was conducted at a large, urban high school in the Midwest. Participants included forty-four students across three science classes during Spring 2014. The content of the three courses varied from one AP Chemistry course to two Integrated Chemistry/Physical Science (ICP) courses. We included all three classes in our study to account for different student experiences with and attitudes towards science.

Design Challenge

The design problem presented to the students, named the Solar House Design Challenge, is set in 2020 where legislation dictates new homes must consume nearly zero energy. To that end, the challenge encourages students to consider solar energy in designing an energy efficient model house that maintains a comfortable interior temperature in both summer and winter. Design criteria are presented in Table 1.

Table 1 - *Solar house design challenge criteria*

Criteria	Description
Energy	Minimize energy needed to keep the building comfortable on a sunny day or a cold night. Consume less than 8,000 kWh of energy per year.
Cost	Minimize total cost of the building. Cost cannot exceed $50,000 in building materials.
Size	Comfortably fit a 4-person family (approximately 185.8 m^2). The house's platform must not exceed the 28 x 36 m platform provided in the software.
Attractiveness	Has attractive exterior or "curb appeal"

Students used a computer-aided design (CAD) software, Energy3D, to design solutions for the design challenge while addressing the following engineering principles outlined in the Next Generation Science Standards (NGSS).[4]

- HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Data Sources

The Energy3D system includes a note component that allows students to enter electronic notes concurrent with their designing. During the classroom implementation, students were encouraged to note their design process, decisions and thinking and were instructed to take notes "like an engineer." Notes could include information such as reasons for creating or selecting design features, describing tests to conduct about the performance of the current design, documenting performance and interpreting test results, and making plans for next steps. The student design rationales, collected through electronic notes within the system, were used in conjunction with the process data to gain a much clearer picture of student actions, learning and reflection.

In addition, data from each design including total construction costs, total area, total energy consumption (kWh) available from Energy3D analytics was used to determine which homes met all design criteria.

Data Analysis

Content analysis was employed as the methodological approach to systematically categorize large amounts of data from 44 students with three designs each for a total of 132 designs. In this systematic characterization, the researchers identified the unit of analysis to be the 132 potential reflections. Students took reflective notes during and at the conclusion of their design process within Energy3D.

Each design reflection (one per student, per design) was coded with respect to three distinguishable areas in the coding scheme (see Table 2). These a priori codes were tested on a small dataset through previous iteration.[6] Two code areas were selected by the researchers based on learning objectives of the design activity to make science connections through design and to draw on data to make informed conclusions. The third code, balance benefits and tradeoffs, was selected as a code of interest because a previous exploratory study by the authors[6] showed a connection between students' balancing benefits and tradeoffs and making connections to science concepts. *Science concepts* refers to explicit mention of science concepts or scientific explanations for design decision or house energy performance. These concepts could include heat transfer, seasonal solar path, the relationship between building geometry and the solar energy gains. *Data* is the explicit mention of hard data from Energy3D including construction costs and energy consumption. Finally, *balance benefits and tradeoffs* involves comparing energy performance in summer vs. winter, especially with respect to performance of a specific design feature (i.e. windows, trees, solar panels, roof, etc.) or specific mention of consideration of minimizing construction costs and minimizing energy consumption.

Each reflection was coded with respect to the variables in the coding scheme (see Table 2). Two analysts independently coded each reflection, compared their codes and resolved all inconsistencies. The average reliability for coding across all three codes was 87.1% prior to resolving inconsistencies.

Table 2 - *Coding scheme for student reflective notes*

Criteria	Description
Science concepts	Explicit mention of science concepts or scientific explanations for design decisions or house energy performance. These concepts could include heat transfer, seasonal solar path, and the relationship between building geometry and solar energy gains.
Data	Explicit mention of hard data from Energy3D including construction costs and energy consumption.
Balance benefits & tradeoffs	Comparing energy performance in summer vs. winter, especially with respect to performance of a specific design feature (i.e. windows, trees, solar panels, roof, etc.). Student might explicitly mention the positives and negatives about their design within a particular season. Specific mention of consideration of minimizing construction costs and minimizing energy consumption.

We counted the number of codes within each reflection. The coding scheme allowed us to determine the number of times students reflected on science concepts and hard data in designing their homes and how many times students considered tradeoffs when reflecting on their designs.

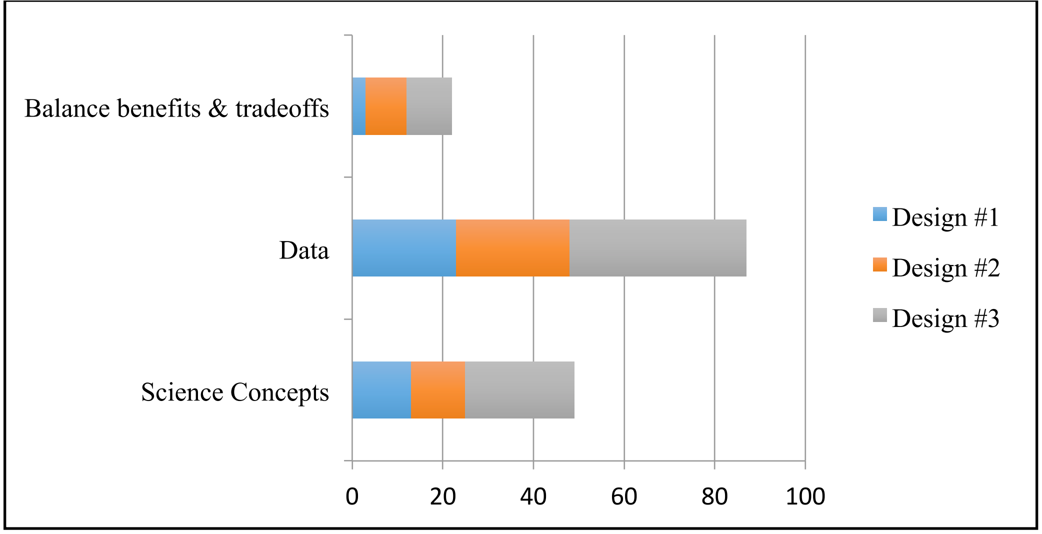
Findings/Results

Trying to understand the role reflective explanations have in students' design through the coding of the reflections resulted in two assertions:

Finding 1: The total number of reflections increased in all three areas with iteration (i.e., students reflected in greater quantity from design #1 to #2 to #3)

Figure 1 depicts the coding of reflections in balancing benefits and tradeoffs, data, and science concepts. For each of these codes, the number of reflections in that area increased with each subsequent design. This shows that students became more reflective with increased iteration.

Figure 1 - Frequency of Student Reflection Codes



Finding 2: Students were more likely to cite data in their reflective explanations.

As seen in Table 3, students were more likely to include data references in their reflective explanations than the other codes. In fact, data references accounted for over 50% of the total reflections for each design.

Table 3: *Categorization of Student Reflections*

Design	Science concepts	Data references	Explicit balancing benefits & tradeoffs
Design #1	13	23	3
Design #2	12	25	9
Design #3	24	39	10

The following is an example of a student reflection that refers only to data:

> *The construction cost of the house is $27691. The net energy of the house is 7665.*

The following reflection mentions both data as well as balancing benefits and tradeoffs (i.e., energy vs. budget).

> *I would have added a more of each [solar panels and trees] but I didn't want to go over budget seeing that I was already at $48,601. Although the price of my house was a little higher than I wanted it to be my house was very energy efficient.*

Discussion and Conclusions

Students were more reflective, in general, in progressing through their three designs. This seems to make sense as "coupled iterations"[7] in the classroom or iterations that involve problem and solution decisions help students behave more like informed designers. In fact, working through iterations allows students to reflect back on problem framing as beginning high school designers often jump straight to problem solving in the first iteration of a design. These students tend to oversimplify problems early in the design process but then discuss higher level function features of their designs later in the design process.[7] So, as high school students develop quality design solutions to meet multiple design criteria they show an increase in explanatory behaviors with increased iteration.

Students cited data in their reflective explanations more often than forming scientific explanations or analyzing trade-offs. This finding confirms previous studies suggesting students have difficulty differentiating between data and evidence, tending to only include data in their arguments.[8] In addition, students are perhaps more comfortable with factual information and a traditional positivist view of science education as "Science in schools is commonly portrayed from a "positivist perspective" as a subject in which there are clear "right answers" and where data lead uncontroversially to agreed conclusions."[5(p288)]

In summary, this study shows students became more fluent in their explanations over time; however, these explanations were more related to factual information and data rather than analysis of trade-offs or buildings scientific arguments. With practice (i.e., with increased number of designs) students provided a greater number of reflections. This suggests the need for students to practice thinking through design issues and writing their arguments to better make science connections and trade-off decisions. Such explanations are critical to developing their understanding of scientific principles.[5(p298)]

By reflecting on design action[9,10], students can start to make sense of science concepts in design activities. Educators should help students explicitly state their decisions, and the implications of their decisions in informing their design goals. [11(p101)] Reflection is one key way to help develop students' ability in explanatory behaviors leading to greater science and engineering learning. Future research should focus on examining this proposed relationship between reflection and learning in the context of solving design problems.

Future research on students' prior math and science backgrounds should be considered.

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