Understanding Science Learning Through Writings on Engineering Design

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Abstract: Engineering design is often used to teach science, but not-yet leads to solid learning gains. We examined the relationship between science learning and engineering design using text mining. Association rule mining was applied to texts written during design to extract the relationships between solar-energy concepts and solar design performance. Findings suggest that students test concept-related factors' effects on design outcomes to learn concepts and eliminate misconceptions. These findings have implications for future instructional design.

Introduction

The National Academies' report on curriculum reforms states, "Engineering design should be the central approach for teaching and learning science" (2018, p. s4). However, research on classroom implementations shows a design-science gap: Students gain design skills but underperform on science learning (Carroll et al., 2010; Crismond, 2001). Students put great efforts into building artifacts (Carroll et al., 2010), reducing the activities into crafting. When asked to explain why the artifacts work, they showed a fragmented understanding of science concepts (Crismond, 2001). An in-depth analysis of students' science learning through engineering design can lead to new strategies for science teaching. In this paper, we use the texts students generated from engineering design activities (i.e., the design plan and review) to investigate their science learning. As Carley (1997) pointed out, texts contain "a portion of the author's mental model at the time the text was created" (p. 536), making them valuable data sources for probing into concept changes in the mind. Association rule mining, which has been used to discover relations among elements (Berka, 2018), is applied to the texts. Specifically, we compare the association rules between students who did and who did not improve conceptual learning after design to shed light on their learning process. To guide the analysis, we asked: (1) Whether association rule mining can capture conceptual changes from writings describing engineering design? (2) If yes, how do students differ in their design behaviors to trigger such conceptual changes, as revealed by association rules?

Methods

A total of 208 students from five high schools in the midwestern US participated in the study. Removing students missing parental consents or test scores leaves a sample of 93 students (51 females). Students used Energy3D, a computer-aided design tool to construct and analyze green buildings, for the engineering design tasks (Xie, Schimpf, Chao, Nourian, & Massicotte, 2018). Students were challenged to complete three tasks of optimizing electrical output by changing the location and settings of solar panels. The pre/posttest included multiple-choice questions for conceptual understanding and open-ended questions on design plan/review. The scores of the multiple-choice questions were used to calculate learning gain. The writings on design plan/review were used as the texts for association rule mining. Questions on the design plan asked for prospective strategies for solving each of the challenges, and the review questions were about the strategies they employed.

Students were divided as the learning-gain (LG) and no-learning-gain (NLG) groups. The LG group had 37 students who answered at least one more question correctly in the posttest than in the pretest, while the NLG group consists of the 56 students who had no improvement or a drop in their posttest. Association rule mining was applied separately to LG-pre-design, LG-post-design, NLG-pre-design, and NLG-post-design texts. The mined rules were formed as $X \Rightarrow Y$, meaning that X and Y both present in texts. The probability of a rule was measured by its *support*, *confidence*, and *lift*. Minimum support and confidence were set at 0.04 to exclude trivial rules. The lift was set as larger than 1 to find positive associations.

Results and discussion

The LG group emerged new rules in the post-design writing, suggesting that the students gained new knowledge through design. For example, the occurrence of "south" in writing implies the conceptual understanding of

Sun's path (i.e., sunlight generally comes from the south at the northern hemisphere). Before design, there were no rules on "south" in both groups. After the design, seven such rules emerged in the LG group (Table 1). One LG student mentioned "south" twice in the post-design writing: "[Task 1] I would …put it on the south side… [Task 2] …It would also have a larger slanted roof facing the south so that I could put a lot of solar panels on it." The absence of rules in the NLG group suggests that these students had no such prior knowledge and failed to obtain it during design. In the rules, "south" frequently co-occurred with "solar panel" and "tilt." This occurrence implies that students learned the concept by their design actions of putting solar panels on the south-facing roof and tilting panels to face south. Design activities provide a chance to learn a science concept as they offer real-world evidence on what will happen when the concept is applied to the design. By finding the fact facing solar panels to the south increases electricity output, students gained knowledge.

Results also showed that the students of the LG group eliminated misconceptions after design. For example, Some LG students had a misconception before design that positioning the panels facing east or west (instead of the south in the northern hemisphere) can benefit the electricity output (Table 1). This misconception disappeared after they completed the task. An LG student planned to "put solar panels facing the west/up." He/she improved the strategy after the design: "Putting the panel facing the south side ..." In contrast, the NLG group had zero rules before and after the activity. The reason why design can remove misconceptions is that when students try the misconception in design, the evaluation will show them the outcome is poor. When students test the idea of facing panels to east or west, the evaluation shows that it cumulated less energy over the day than facing south, as the Sun rises from the southeast and sets in the southwest. When students recognize this, they got rid of the misconception and upgraded their knowledge.

To sum up, the findings described how students learn from engineering design and provide insights for designing better curricular instructions. Also, this research provides a method that leverages the use of broadly available but overlooked data – student writings on engineering design. A natural progression of this work is to apply the method to other engineering design tasks to examine whether a similar learning pattern can be found.

Table 1: Association rules of "south" and "west/east" mined from the student writing.

Rules of south after design	Supp	Conf	Lift	Rules of west/east before design	Supp	Conf	Lift
south ⇒ tilt	0.05	0.67	4.63	east ⇒ west	0.06	1.00	13.88
tilt ⇒ south	0.05	0.38	4.63	west ⇒ east	0.06	0.88	13.88
south ⇒ solar panel	0.06	0.78	1.33	west ⇒ solar panel	0.05	0.63	1.20
solar panel ⇒ south	0.06	0.11	1.33	solar panel ⇒ west	0.05	0.09	1.20
south, tilt ⇒ solar panel	0.05	0.83	1.42				
solar panel, south ⇒ tilt	0.05	0.71	4.96				
solar panel, tilt ⇒ south	0.05	0.45	5.61				

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