The Interplay Between Design Strategies Use and Design Performance

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Abstract: Various research efforts have been put into understanding design strategies performed by novice designers versus informed designers, misconceptions and challenges in design, as well as design teaching strategies, just to name a few. However, the work on operationalizing design strategies as a form of assessment still remains largely unexplored. In this study, we aimed to (a) investigate ways to operationalize design strategies using process data, and (b) study the interplay between students' design strategies use and their design performance. The design strategies we targeted were generating ideas and troubleshooting.

Background

Engineering design is defined as *"the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specific constraints"* (Dym, 1994. p.17). The process of engineering design is not a straightforward one - it is often very complex and requires designers to take strategic design strategies in order to do it well (Dym, Agogino, Eris, Frey, & Leifer, 2005). With its increasing importance and popularity in education, research efforts have been put into better understanding the different design strategies applicable to engineering design, challenges in learning them, as well as pedagogical strategies to teach them (e.g., Atman, Cardella, Turns, & Adams, 2005; Crismond & Adams, 2012). Even though there has been some efforts on assessing idea fluency and experimentation through the student design process by exploring design replays and process data (Goldstein, Purzer, Mejia, Zielinski, & Douglas, 2015; Vieira, Hathaway Goldstein, Purzer, & Magana, 2016; Vieira, Seah, & Magana, 2018), efforts on operationalizing design strategies as forms of assessment or formative feedback, still remain largely unexplored.

The advancement of digital educational technologies have opened more doors for computer-based assessment and learning analytics (Klašnja-Milićević, Ivanović, & Budimac, 2017). One of the main advantages of these technologies is their ability to unobtrusively collect process data (Xie, Zhang, Nourian, Pallant, & Hazzard, 2014) that can later on be used for assessment or feedback purposes. In our study, we would like to explore ways that we can operationalize students' design strategies using process data generated from an educational CAD tool. Besides, we would also like to study the interplay between students' design strategies used and their design performance. The design strategies that we attempted to operationalize in this study are generating ideas and troubleshooting. The research questions are (a) how can the strategies of generating ideas and troubleshooting be operationalized using process data? and (b) what is the interplay between students' design strategies use and their design performance?

Methods

Participants of this study included ten first-year undergraduate students, three from engineering majors and seven from engineering technology majors. These students participated in this study voluntarily for a one-and-a-half-hour-long session. During this session, students were asked to complete a design challenge where they had to build an energy efficient home using a CAD tool called Energy3D (Xie, Schimpf, Chao, Nourian, & Massicotte, 2018), while fulfilling certain constraints and requirements such as the area of the house must be around 200 m^2 and the budget for the house cannot exceed \$200,000. The data source we used was the logged students' clickstream data (herein referred as process data) by Energy3D, in the form of JSON files. Energy3D does not automatically classify actions based on design strategies and therefore, we had to define and operationalize the types of actions to include for the strategy assessments based on strategy descriptions grounded in literature.

Generating ideas was operationalized as strategies that explore the design space using approaches such as brainstorming to prevent idea fixation since the beginning in problem solving. In order to quantitatively measure how students generated ideas, we calculated the total number of generating ideas actions performed by students. Generating ideas actions are a combination of construction actions and parameter actions ("The JSON Data Schema", 2016). This combination of actions was chosen because we deemed to best represent all the instances where students were exploring the design space using these various tools and actions. In addition, we calculated the performance of generating ideas in percentages by using the following formula:

$$\text{Generating Ideas Performance} = \frac{\text{Sum of generating ideas actions done by students}}{\text{Highest sum of generating ideas done by students}} \times 100\%$$

Troubleshooting was operationalized as a strategy that helps designers to propose ways to fix the problems they are facing. In order to quantitatively measure how students efficiently used troubleshooting strategy, we calculated the number of different analysis tools used by the students, using analysis actions ("The JSON Data Schema", 2016). This combination of actions was chosen because we deemed to best represent students' diagnosing and troubleshooting ideas based on the use of analysis tools to test their design choices. In addition, we calculated the total number of times these analysis tools were used. With these information, we calculated the performance of troubleshooting in percentatges by using the following formula.

$$\text{Troubleshooting Performance} = \frac{\text{Sum of analysis tools used by students}}{\text{Highest sum of analysis tools used by students}} \times 50\% + \frac{\text{Sum of times all analysis tools used by students}}{\text{Highest sum of times all analysis tools used by students}} \times 50\%$$

Once we obtained the aforementioned percentages, we classified students based on their competency level for each design strategy using the rubric presented in Table 1 below. The segmentation of scores (%) for each level of competency was decided using the standard grading scale (e.g., A: 90 – 100% and F: 0 – 59%).

Table 1: Rubric for students' competency levels on different design strategies

	Beginning	Emerging	Developing	Proficient	Advanced
Generating ideas	0-59% of total generating ideas performance	60-69% of total generating ideas performance	70-79% of total generating ideas performance	80-89% of total generating ideas performance	90-100% of total generating ideas performance
Trouble-shooting	0-59% of total troubleshooting performance	60-69% of total troubleshooting performance	70-79% of total troubleshooting performance	80-89% of total troubleshooting performance	90-100% of total troubleshooting performance

We also measured students' final performance by considering elements of their final solutions including the area, final cost, and final annual energy consumption of their final home design. Each of these criteria were weighted equally to make up a 100% (i.e., 33.33% each).

Results and discussion

Figure 1 depicts students' performances in the strategy of generating ideas and Figure 2 depicts students' performances regarding troubleshooting. For both Figures, the x-axis represents each student and the y-axis represents the students' performance in each strategy in percentages. Based on Figure 1, S2 and S7 had the highest performance in generating ideas (i.e., both 100%) whereas S3 had the lowest performance (i.e., 57%). Based on Figure 2, S7 had the highest performance in troubleshooting (i.e., 90%) whereas S1 had the lowest performance (i.e., 56%).

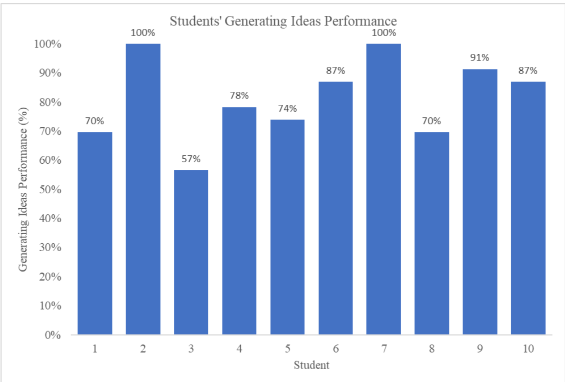


Figure 1. Students' generating ideas performance.

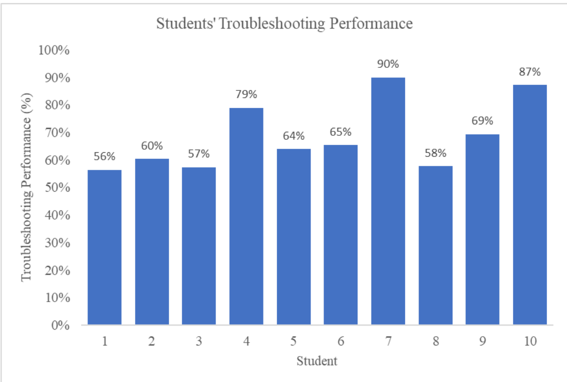
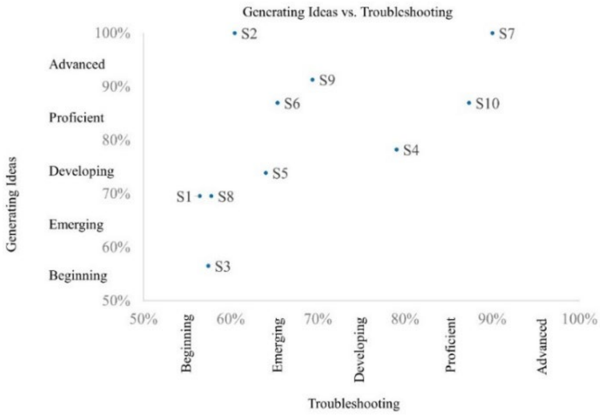


Figure 2. Students' troubleshooting performance.



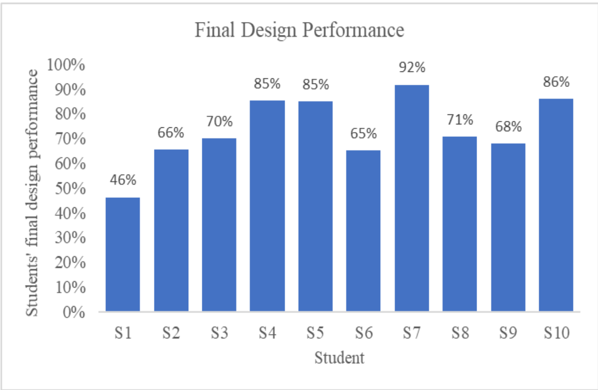


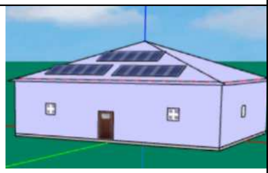
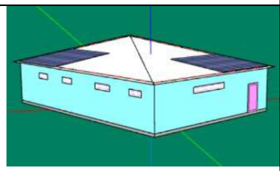
Figure 3. Students' performance in generating ideas and troubleshooting.

Figure 4. Students' performance in the final design solutions.

Figure 3 depicts the interplay between students' performance in generating ideas and troubleshooting. Based on Figure 3, students who had low performance in generating ideas also had low performance in troubleshooting. The opposite is also true. For example, S3 fell under *Beginning* level in both strategies whereas S7 fell under *Advanced* level in both strategies. Next, we studied the interplay between students' design strategies use and their final performance. As shown in Figure 4, S1 had the lowest performance, S7 had the highest performance, and S6 and had a moderate performance. When compared with Figure 2, it can be found that students who often performed better in both generating ideas and troubleshooting continued to perform better in their final design. The opposite is also true. An interesting case is S2 who generated a lot of ideas, but did not engage often in troubleshooting.

To exemplify some final designs, in Table 2, we provide three designs at three different performance levels (i.e., fair, good, and excellent) to demonstrate this finding. For example, S1 scored 70% in generating ideas and 56% in troubleshooting also scored a low score (i.e., 46%) in final design performance. On the other hand, another example shows that S7 scored 100% in generating ideas and 70% in troubleshooting also scored a high score (i.e., 92%) in final design performance. However, as shown in Figure 4 for S2, it appears that effectively using one single strategy was not enough for a good final design. A possible explanation for this observation is that, even though effectively using the strategy of generating ideas is useful, the ability to detect flaws in a design through troubleshooting can further inspire new ideas for useful fixes, or even additions of new features, to improve the final design (Crismond & Adams, 2012). In other words, the ability to observe unexpected outcomes of a design during troubleshooting can push for a more effective reconceptualization of the design requirements and constraints (Wills & Kolodner, 2019), and potentially a better final design.

Table 2 Students' final design performance

Performance	Fair	Good	Excellent
Final Design			
Student	S1	S6	S7
Area (m^2)	192	168.1	164
Cost ($)	588,856	181,208	196,426
Annual Net Energy (kWh)	-3296	-1641	- 7713
Design Performance (%)	46%	65%	92%

Conclusion and future work

In conclusion, this study suggested ways to operationalize the strategies of generating ideas and troubleshooting using process data. This study also proposed a method that can be used to classify students' competency level of each design strategy (i.e., generating ideas and troubleshooting). In addition, the results of this study suggest that students' performance in generating ideas is directly proportional to that in troubleshooting, and that these performances have a direct and positive influence on students' final design performance. That is, students tended to show better performance in troubleshooting if their performance is good in generating ideas, and that consequently reflected in better final design performance. Even though this work is still in its early stage, we believe findings are encouraging to characterize design strategies use and their relationship with design performance. Limitations of this study include a small sample size and insufficient types of assessments to capture the full breath of what design encapsulates. In addition, we acknowledge that a certain type of actions could be used to analyze other strategies that are not currently covered in this study. For future work, we plan to increase the sample, explore computational ways to classify and count actions, include more design strategies such as experimenting, revising and iterating, as well as addressing the potential issues of using the overlapped actions for different strategies.

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