Assessing the Engineering Identity in CAD Simulated Engineering Design Challenge

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Abstract

This study investigates high school students' engineering identity while they were challenged by an engineering design task. New academic standards in the U.S. call for integrating engineering into K-12 education; as educators, it should be our priority to engage students with engineering instruction, especially those who were underserved, underperforming, and underrepresented in STEM fields. Engineering identity is referred to students' self-identification, belonging to a community. It is related to students' educational and professional persistence and students' impact on their self-identity. This study measured students' engineering identity development through self-recognition, interest, and performance in engineering design by using their self-reported post-survey questionnaires after they were engaged with an engineering design task. We have also explored the correlation between the students' self-recognition, interest, and engineering design performance. Our results show that there is a high correlation between students' interest and performance in engineering design. Moreover, students with high interest also have a high performance and high self-recognition in engineering design and vice versa.

Keywords: Engineering Identity, Interest, Performance, Self-recognition

Introduction

The Bureau of Labor Statistics (BLS 2018) projects employment growth for engineers over the 2016 - 2026 decade [1]. However, some new studies show declining interest among students in the U.S. to pursue careers in science, technology, engineering, and math (STEM) related field [2]. Therefore, it is vital to encourage students' engineering identity development from an early age to explore their interest in engineering to guide them to pursue careers in engineering. One way to increase students' interest and motivation in engineering are to use project-based learning to learn in a more contextualized environment and improve the sense of ownership in engineering through engineering design tasks [3]. Engineering design is a systematic and iterative process of planning, modeling, testing, and improving products and processes. Due to its complexity and open-endedness, appropriate ways of engaging students in engineering design are needed for quality teaching and learning. Further studies have found that interacting in engineering design using a design-based learning framework to let students use a CAD simulated environment to work on several engineering design challenges will increase their engagement, motivation, and interest in learning engineering design [4]–[6].

This study profoundly explores the self-beliefs in students' engineering identity formation in terms of students' self-recognition, performance, and interests in engineering design after they were engaged through six days of the engineering design task. Students' perception of how their peers saw them and how they see themselves is crucial for them to develop early careers in engineering through recognition [7]. Students' interest in engineering design is also a necessary element of engineering identity development [8], [9]. Their interests and emotional engagement will increase their motivation in engineering design. It defines earlier in a student's life whether they will take on the role identity as an engineer. Students' performance beliefs are a vital component of engineering identity development and engineering choice. Students' self-efficacy beliefs about their ability to perform well in engineering design tasks significantly impact their ability to see themselves as a person who can pursue a career in engineering [10]. Thus, recognition, interests, performance very well measure the engineering identity developed by students [11]–[13].

This study examines students' engineering identity in terms of self-recognition, interests, and engineering design performance after students were experienced working on an engineering design challenge. Students were asked to indicate their level of agreement with their attitude toward learning and a sense of belonging in engineering design through nine post-survey questions. Our research questions were

1) What are students' self-reported level of interests, performance, and self-recognition while working on a CAD-enabled engineering design challenge?

2) How do students' interests relate to their performance and self-recognition in engineering design while working on an engineering design challenge?

Background

In this study, we used a project-based learning approach to engage students in an engineering design task to foster design thinking. Project-based learning and CAD-simulated tool will be discussed below.

Project-based learning

Project-based learning (PBL) is a student-centered dynamic classroom approach where learners acquire knowledge and skills by exploring a real-world challenge, problem, or complex question for an extended period of time [14]. PBL provides an opportunity for students to engage with the content deeply and improves students' attitudes toward learning by keeping them engaged with the project for an extended period of time. PBL has been showed to be effective in helping students improve their understanding of science principles underlying a problem or project [15], [16] and also improve their engineering skills such as problem solving and innovating [17]–[19]. In addition, research also shows that project-based learning affects students' development of engineering identity [20].

CAD-Simulation tool

The technology used to support project-based learning was recommended by various researchers to increase students' motivation and interest in engineering design [21], [22]. When paired with project-based learning, CAD simulation tool allows students to engage with the problem at hand more interactively, by providing platforms for experimentation in a more visual and time effective way [23], [24]. The CAD tool is a simulation-based engineering tools for designing green buildings and power stations that harness renewable energy for a sustainable environment [25]. In this study, students were asked to solarize their own school by using a CAD software in a project-based learning classroom. After they were experienced using the CAD tool for six days, they were asked about their engineering identity with a post questionnaire (See Table 2).

Methods

Participants

Participants of this study included 96 ninth-grade students (38 females, 58 males) from a suburban high school in the Northeast U.S. (27% African American, 10% Hispanic, 35% economically disadvantaged; 19% first language not English) in fall 2019 in Science of Energy courses. These students were invited to participate in a six days long study voluntarily. Students were challenged to solarize their school, which was given to them as a 3D model using a simulation-based CAD tool for designing 3D buildings and power stations [25]. The school building model was provided to the students, they were only required to design solar arrays. These students were given particular constraints and requirements as part of the challenge, such as their solarized school should generate more than 400,000 kWh of electricity per year with a payback period shorter than ten years, and the house's upfront cost which refers to the solar panel infrastructure should not be more than $800,000. The data source we used for the analysis consisted of their post-survey consisted of 9 questions related to their interest and enjoyment, self-recognition, and performance/competence in engineering design.

Procedures

This study was conducted in 6 sessions with three school teachers who precisely applied the same design tasks. A typical design task was implemented as described in Table 1.

Table 1. Design implementation plan for 6 days

Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**

Warmup 43 mins	Science 43 mins	Science 68 mins	Optimize 43 mins	SYS 43 mins	SYS 90 mins

- Science = science concepts learning through the CAD tool
- Optimize = Optimize your design using the CAD tool
- SYS = Solarize your school using the CAD tool

The project was implemented in the regular class sessions for six days. The project contained two parts - science learning and the design challenge. The science concepts covered in the curricular unit included the sun's path, the projection effect, the effect of the air mass, the effect of weather, and solar radiation pathways. Students learned the concepts by first working on simple problems that only involved one concept and then worked on a complex issue that integrated all concepts. After science learning, students were given a design task customized to their context - Solarize Your School. The task background was a competitive bid held by the town their school was located in. The bid asked for cost-effective solutions to turn the school building into a power generator. Students were given a 3D model of their school and could add solar panels on the school building roof to generate solar energy. The design goal was to create a solar array design that could generate more than 400,000 kWh of electricity per year with a payback period shorter than ten years. During the project, students worked individually on their laptops. After finishing the project, all the students filled a post-survey related to their engineering identity and emotional engagement.

Design Challenge

In this study, students were tasked with completing a design challenge to solarize their school using a CAD tool while fulfilling some design requirements and constraints. Their town was calling for bids to power their school with solar energy. As a solar engineer, they would design cost-effective solutions that turn the school building into a power generator to meet the challenge. The requirements and constraints of this design challenge were as follows:

- Types of solar panel: Their town has negotiated with three manufacturers, which offered three different types of solar panels, as shown in the following figure (see Figure 1). They must select one and only one of them for their project. The prices listed in the table have factored in the insurance cost, the installation cost, and other costs.

- Budget limit: The total upfront cost of the solar panels, racks, and supporting systems must not exceed $800,000.
- Installation location: The solar panels must be installed on and within the roofs. Chimneys, vents, and heating and cooling equipment on the roofs must be left open and accessible.

Manufacturer Model	SunPower SPR-X22-370	Yingli YL375D-36b	Canadian Solar CS6X-355P-FG
Cost per Panel ($)	$590.00	$589.00	$529.00
Power Output (Watt)	370W	375W	355W
Solar Cell Efficiency	22.7%	19.29%	18.18%
Dimension	1.04m x 1.55m	0.99m x 1.96m	0.99m x1.96m

Figure 1: Types of Solar Panel

Data Analysis Method

Data analysis of this study is based on the descriptive and inferential statistics of the post-survey items which was adapted from [26]. First of all, all survey responses from strongly disagree to strongly agree were converted to the numbers from 1 to 6 as one being strongly disagree, and six being strongly agree. Then nine survey questions were categorized as self-recognition, interest, enjoyment, and performance/competence constructs using the engineering identity measurement developed by [11]. Table 2 shows the post-survey questions and their constructs in engineering identity [11].

Table 2. Post-survey questions and their constructs in engineering identity

I could see more of myself as an engineering designer	Self-Recognition
I enjoy learning engineering design	Interest and Enjoyment
I am interested in learning more about engineering design	
I find fulfillment in doing engineering design	
I am confident that I can understand engineering design in class	Performance/competence

I am confident that I can understand engineering design outside of class	
I can overcome obstacles in engineering design	
I can do well in engineering design tasks	
Others ask me for help in this solarize your school project	

Then students' interest, self-recognition, and performance/competence in engineering design scores were calculated based on the post-survey responses. The statistical results were presented in the results section.

Results and Discussion

This study's results were explored based on students' interest, performance, and self-recognition in engineering design. Descriptive statistics for students' interest, performance, and self-recognition were determined and represented in Figure 2.

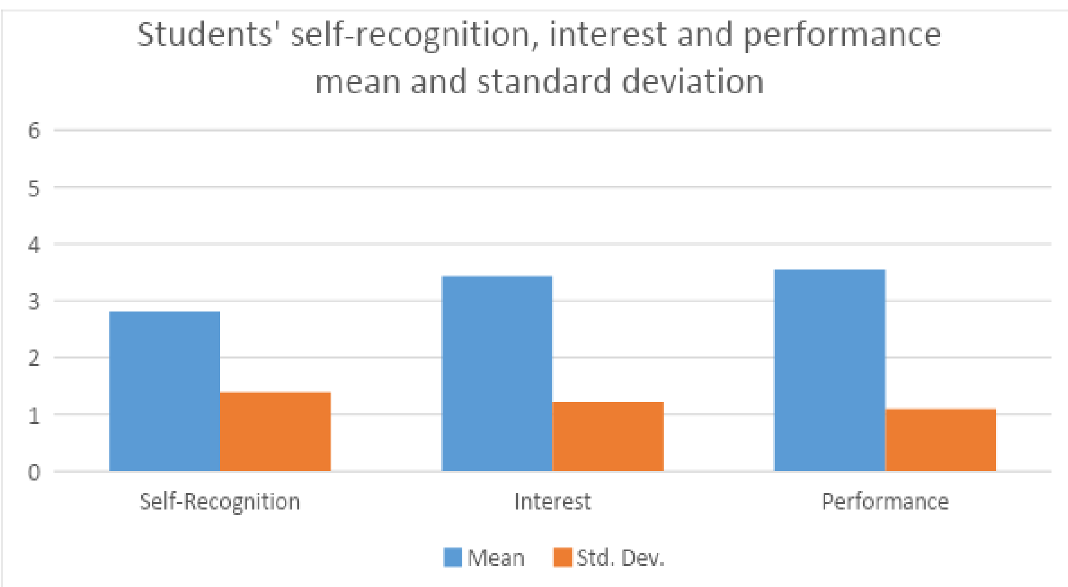

Figure 2. Students' self-recognition, interest, and performance mean and standard deviation from the post-data. Numbers on the y-axes represent the following as 1: Strongly Disagree, 2: Disagree, 3: Somewhat Disagree, 4: Somewhat Agree, 5: Agree, 6: Strongly Agree.

As shown in Figure 2, students' performances were higher than their interests and self-recognition overall. Students' self-recognition was scored lowest, which could potentially suggest that student's awareness about their engineering identity needs to improve. They might be underestimating their engineering identity through self-recognition.

Table 3. Pearson correlation coefficients between the self-recognition, interest, and performance

Engineering Identity Themes	Self-Recognition	Interest	Performance
Self-Recognition	1		
Interest	0.609443115	1	
Performance	0.496804195	0.760067414	1

Table 3 shows the Pearson correlation coefficients of students' self-recognition, interest, and engineering design performance. The result in Table 3 indicates a high correlation between students' interest and performance in engineering design (i.e., r = 0.76). Similar result is also reported in literature [27]. In addition, the correlation between the students' self-recognition and interest (i.e., r = 0.61) as well as self-recognition and performance (i.e., r = 0.49) in engineering design was moderate.

Based on these results, students were divided into three categories as students with high interest ($interest\ score \geq 5$), medium interest ($3 \leq interest\ score < 5$), and low interest($interest\ score < 3$) in engineering design. There were 11 students with high interest, 60 students with medium, and 25 students with low interest in engineering design. Then we explored to see if students with high, medium, and low interests in engineering design also have high, medium, and low performances and self-recognition in engineering design. The results are represented in Tables 5 and 6. These results show that students with high interests also had high performance; students with medium interests also had medium performances; students with low interests had a low performance in engineering design. Kruskal Wallis test, which is a non-parametric test was used to determine if there are statistically significant differences between the students' interest, performance and self-recognition. Kruskal-Wallis results also show significant differences between the groups with high, medium, and low performances. (see Table 4)

Table 4. Kruskal Wallis Test between the students' interest, performance, and self-recognition show significant differences.

	Interest	Performance	Self-Recognition
Kruskal-Wallis H	70.78	45.714	26.158
df	2	2	2
p	0	0	0

Table 5. Students' performance scores descriptive results based on their high, medium, and low interests in engineering design.

Groups	Count	Sum	Average	Variance
Performance1-High Interest	11	53.6	4.872727	0.202182
Performance2-Medium Interest	60	227.2	3.786667	0.637107
Performance3-Low Interest	25	60	2.4	0.783333

Similarly, we investigated whether students with high, medium, and low interests in engineering design also have high, medium, and low self-recognition in engineering design, and the results were represented in Table 6. The results show that students with high interests also had a high self-recognition; students with medium interests also had a medium self-recognition. Students with low interests had a low self-recognition in engineering design.

Table 6. Students' self-recognition scores descriptive results based on their high, medium, and low interests in engineering design.

Groups	Count	Sum	Average	Variance
Self-Recognition1-High Interest	11	50	4.545455	0.672727
Self-Recognition2-Medium Interest	60	172	2.866667	1.575141
Self-Recognition3-Low Interest	25	48	1.92	1.326667

The following figure shows the relationship between the three constructs (interests, performance, and self-recognition) in engineering design (see Figure 3). We visualized results of that relationship between the students’ interests, performance, and self-recognition using a Sankey chart shown in Figure 3, which represents the flow where the width of the connections is proportional to the flow rate.

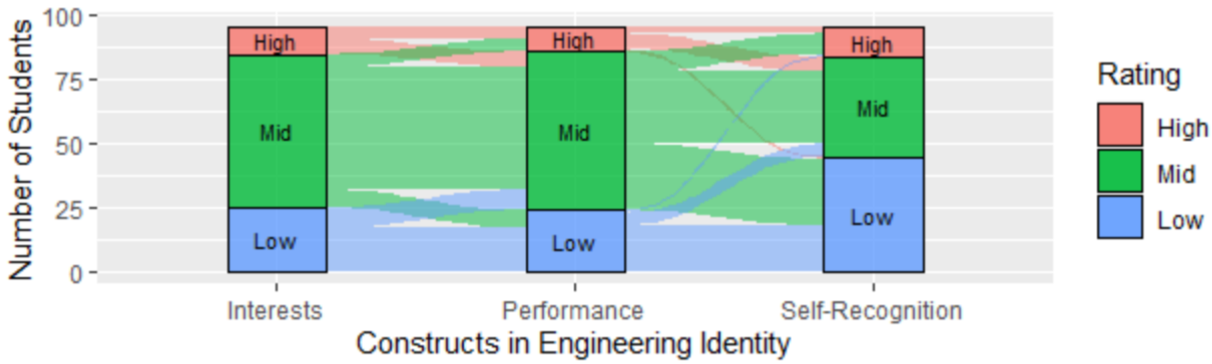

Figure 3. Sankey chart for students’ high, medium and low interests, performance and self-recognition in engineering design.

Findings from this study will bring significant implications in understanding students' engineering identity levels in engineering design as designers, informing educators to assess students' engineering identity more effectively to increase their interest and motivation in engineering design.

Conclusion, Implications, and Limitations

In this study, we have explored students’ engineering identity via the measures of their self-recognition, interest and performance in engineering design using a CAD simulated tool in a project-based learning environment. We have also determined the correlation between the students' self-recognition, interest, and engineering design performance. Our results showed that there is a high correlation between students' interest and performance in engineering design. Additionally, students with high interest also have a high performances and high self-recognition in engineering design. Our results suggest that when engaging in project-based learning, students might increase their interest in engineering design. When they do, it positively impacts their performance and self-recognition as well. This particular finding serves as an encouragement for educators who would like to implement project-based learning in their classrooms to motivate students' interest and performance in engineering design.

Implications of this study include the potential of using project-based learning paired with CAD simulation tool to build students' engineering identities. Moreover, the assessment method used in this study can serve as a starting point for educators who would like to assess the engineering identity of their students. For example, educators can use similar assessment to their students, at the very beginning of their courses to see how they can adjust their pedagogy accordingly if most students are of low interest and assess again at the end of their courses to see if there is any improvement.

We also suggest that the survey questions can be improved by adding some questions related to feeling that others sees them as a good designer for the recognition component. As suggested by [11], we can add the following questions the recognition construct; 1) My parents see me as an engineer, 2) My instructors see me as an engineer, 3) My peers see me as an engineer.

In terms of limitation, we acknowledge that our study does not include a pre-test to allow the assessment of students' changes in terms of interest, performance, and self-recognition, prior and after engaging in the project-based learning activities. Therefore, further studies might include a pre-test and written reflections from the students related to their recognition, interests and enjoyment, performance or competence in engineering design. In addition, we did not have sufficient data to assess students' scientific understanding or engineering performances. Hence, we could not draw conclusions on whether the project-based learning approach in this study improved students scientific understanding and engineering skills.

In conclusion, our results show that project-based learning has the potential of improving students' interest and performance in engineering. Specifically, we learned that students' interest is highly correlated to their performance. Therefore, for educators who are interested in improving students' perception of performance in engineering, it is important to take their interest into consideration. This could include designing activities that are aligned with students' interest. Lastly, we recognize that more effort is needed to help students build engineering identity.

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