

Peer Assessment for Engineering Design Education: An Exploratory Study*

HYUNKYUNG LEE¹, DAEUN JUNG² and HYUNGJIN KIM³

¹ Division of Teaching and Learning, Korea Institute for Curriculum and Evaluation, Jincheon 27873, Korea.

² Department of Educational Psychology & Learning Systems, Instructional Systems & Learning Technologies, Florida State University, Tallahassee, FL, 32306, USA.

³ Department of Electrical and Computer Engineering, Inha University, Incheon 22212, Korea. E-mail: hkim@inha.ac.kr

This study investigated the influence of engineering design classes with peer assessment on learning outcomes and the learners' and instructor's perceptions of peer assessment. For this purpose, 39 college engineering students in the engineering design class at a university in Korea were asked to conduct peer assessments twice. As a result, engineering design classes with peer assessment significantly improved learners' computational thinking, creative problem-solving, and collective efficacy. The learners and the instructor recognized that peer assessment can help develop problem-solving skills and cultivate a mindset as an engineer in the engineering design. However, they commonly noted the problem of insufficient time for assessment activities during class. Some students also doubted their own and their peers' ability as assessors. This study contributed to expanding the understanding of the role of peer assessment in the context of engineering design education.

Keywords: peer assessment; engineering design education; physical computing; computational thinking; creative problem solving, collective efficacy

1. Introduction

Engineering design education is important because it prepares students to be innovative problem-solvers and to tackle the complex, real-world challenges of the engineering profession. Through experiential learning approaches such as collaborative learning, students can develop important skills and competencies, including critical thinking, creative problem-solving, teamwork, and communication. Engineering design education also fosters the development of creative and analytical thinking, as students learn to generate and evaluate design solutions. In particular, recently, attempts to improve engineering design education through physical computing, which refers to creating or using devices that interact with the world around them, are underway (e.g., [1, 2]). However, not all engineering design classes always guarantee high academic achievement [3].

Peer assessment can be used to support learners to experience meaningful learning in engineering design education. Peer assessment refers to an assessment in which students evaluate their colleagues' learning outcomes (e.g., essay, presentation, design artifacts) in the form of a grade [4]. By providing feedback on the work of their peers, students are encouraged to think critically about their own work and the work of others, and to communicate their ideas and thoughts effectively [5–7]. Additionally, by understanding and internalizing the standards of good design through peer assessment, learners can develop design ability [8].

Learners may be able to creatively solve problems through opinions from various perspectives [9].

Despite the expected utility of peer assessment in engineering design classes, few empirical verifications have been made in this regard. Most studies on peer assessment have focused on the assessment of essays or presentations [10], and few have examined the assessment of design artifacts. In addition, peer assessment in engineering design education may show different dynamics from the peer assessment process reported in previous studies because engineering design tasks are different from general design tasks. For example, engineers are expected to base their designs on scientific knowledge and in most cases, the value and performance of engineering designs can be confirmed through quantitative measurements. In addition, the chronic problems of peer assessment pointed out in previous studies, such as low feedback quality, may also be revealed together.

In this study, we explore the application cases of peer assessment in engineering design education using physical computing. To this end, the impact of engineering design course with peer assessment on learning outcomes and students' and instructors' perceptions of peer assessment were explored. The study results can be used as basic data to develop specific peer evaluation strategies in engineering design education in the future. The research questions include:

1. What are the impacts of an engineering design course that incorporates a peer assessment approach on students' learning outcomes?

2. What are the students' perceptions about the peer assessment activity in engineering design class?
3. What are the instructor's perceptions about the peer assessment activity in engineering design class?

2. Literature Review

2.1 *Engineering Design Education using Physical Computing and Educational Robotics*

For professional engineers, the ability to systematically and creatively solve engineering problems by collaborating with colleagues is important. Engineering graduates recognized that data analysis, problem solving, teamwork, and communication competencies are relatively more important among ABET (Accreditation Board for Engineering and Technology, Inc.) competencies in their work [11]. These competencies have been expected to be developed through meaningful, authentic, collaborative engineering design experience. In particular, physical computing which is an emerging instructional strategy for teaching computing concepts by incorporating tangible interfaces in which learners can create real products through programming [12] is an attractive design task to develop core competencies in the context of engineering education. For this reason, some educators offer novice engineers a meaningful learning experience in which they design and develop their own artifacts that interact with the physical world (e.g., [1, 2]). Researchers have examined how the physical computing approach integrated into STEM education settings could influence learning outcomes. They found that physical computing improves students' computational thinking [13, 14], problem-solving skills [15], collaboration skills and intrinsic motivation [16]. However, there are reports that physical computing has a negative effect on academic achievement due to its own complexity requiring both hardware and software programming [3]. Considering the results of these preceding studies, it is necessary to explore what kind of educational interventions can support physical computing activity well in engineering design education.

2.2 *Peer Assessment*

Peer assessment can empower students to be self-regulated learners by involving them in the assessment process [4, 17]. Receiving feedback from multiple peers was found to be more beneficial than that from a single subject-matter expert [18, 19]. Moreover, as peers share the same languages and similar level of knowledge, their feedback may be more intelligible and, thus, more helpful than that of teachers [18]. Students can also benefit from

providing feedback by engaging in certain mental processes, such as critical thinking, taking an assessor's perspective, and reflecting on their own work [7, 18].

Peer assessment, which is the process of evaluating the work of one's peers, can be an effective teaching and learning strategy in engineering education. A few studies on peer assessment have been conducted in engineering education settings. For instance, Chang and their colleagues [20] revealed that online peer assessment can enhance students' inquiry learning, reflective thinking abilities, and LED design skills in well-structured problem solving in a university's physics course. Prior research [9] identified that critical feedback can enhance students' creative engineering design by helping them avoid design fixation. Nicol and their colleagues [7] also found that by engaging in peer assessment, students in a first-year engineering design class were involved in a reflective process in which they compared peers' works with their own work and applied the evaluation criteria to their own work.

However, not all research has found solely beneficial effects of peer assessment. According to prior research [21], peer assessment was ineffective in improving students' academic performance, and students' satisfaction with peer assessment pedagogy was negative. Many researchers have also reported students' concerns about fairness in peer evaluation [22, 23]. Poor quality of peer feedback has also been mentioned as a barrier to implement peer assessment [24]. Such findings highlight the significance of instructional design, thus implying that peer assessment may be successful only when applied within a well-designed curriculum [21, 25, 26]. Therefore, it is important to explore instructional approaches to implement peer assessment in engineering education settings and evaluate what works and what does not.

2.3 *Social Constructivism*

Social constructivism is a theory of learning that emphasizes the role of social interactions and collaborative processes in the development of knowledge and understanding. The social constructivism assumes that learning takes place through social interactions. The social interactions help learners to cross their zone of proximal development (ZPD), which is the cognitive distance between the development level that learners can reach independently and that they can attain with the assistance of more capable others [27].

Engineering design education, which focuses on teaching students how to design and create solutions to real-world problems, can also benefit from a social constructivist approach. Social constructivism suggests that students learn best when they are

actively engaged in collaborative learning experiences, in which they can discuss and reflect upon their ideas with their peers [28]. By working in collaborative groups, students can learn from each other and draw on the diverse perspectives and expertise of their peers to inform their design process. This type of hands-on, experiential learning can help students develop important skills and competencies that are essential for success in the field of engineering. For this reason, collaborative learning has been adopted in engineering design courses in various forms, including computer-supported collaborative learning [29, 30], simulation games [31], and collaborative problem solving [32].

Additionally, according to the social constructivism, cultural artifacts play a significant role in social interactions. In this sense, learning can be considered participation in a community of learners that share sociocultural endeavors [33]. Peer assessment can foster a sense of community and collaboration within the classroom because they are all contributing to the evaluation and improvement of each other's work. This can create a more engaging and supportive learning environment, which can be beneficial for students' overall learning and development. Further, peer assessment provides opportunities for students to participate in the cultural practices of the professional engineer community. One of the cultural practices in the community of professional engineers is to receive feedback from different stakeholders to improve their design quality. Thus, the peer assessment component can provide students with the opportunity to experience a cultural practice that can be found in the community of engineering design practitioners [34]. From the perspective of social constructivism, peer evaluation of engineering design is expected to be educationally meaningful.

3. Research Methods

3.1 Participants

Students of the engineering design class, introduced as a first-year class in the second semester of 2019 at Y University in South Korea, participated in the

study. There were 39 students, but three students who did not participate in the peer assessment were excluded from the data analysis; finally, the data of 36 students were analyzed. More than half of the students who participated in the research were male (female = 12, male = 24), and the average age was 19.44 years ($SD = 1.4$). Most of the students had no prior experience with physical computing (no experience = 31, experience = 5).

3.2 Procedure

For a semester (15 weeks), 11 teams of three to four members performed the task of designing a line tracing program using Lego's Mindstorm EV3. Students were asked to respond to the pre-survey in the first week and post-survey after the end of the course. An orientation session was held to guide them about the course and peer assessment activity for the first two weeks and familiarize them with the basic functions of Mindstorm EV3. The task was divided into Project 1 and Project 2, six weeks' duration each, for a total of 12 weeks, with a week's break between the projects. Each project consisted of a four-week long design stage, a week-long test stage, and a week-long presentation stage. After the course, the instructor was interviewed.

Mindstorm EV3 and line map units were provided to help students design and test line tracing programs for physical computing. The Mindstorm EV3 is a Lego robotic system comprising sensors, engines, Lego pieces, and programmable bricks. The coding language of Mindstorm EV3 is a block coding language that codes through flow diagrams instead of text. A Mindstorm EV3 core set comprising a controller, motor, battery, sensor (gyro, touch, color, and ultrasonic sensor), and Lego pieces was provided to each team.

Each project for developing line tracer using Mindstorm EV3 consisted of design, test, and presentation stages. In the design stage, students collaboratively developed a prototype using line map units. Basically, each unit is made by painting a hardboard with a black background and white lines. Units consist of line units with only a line and intersection units with a right turn green mark or a

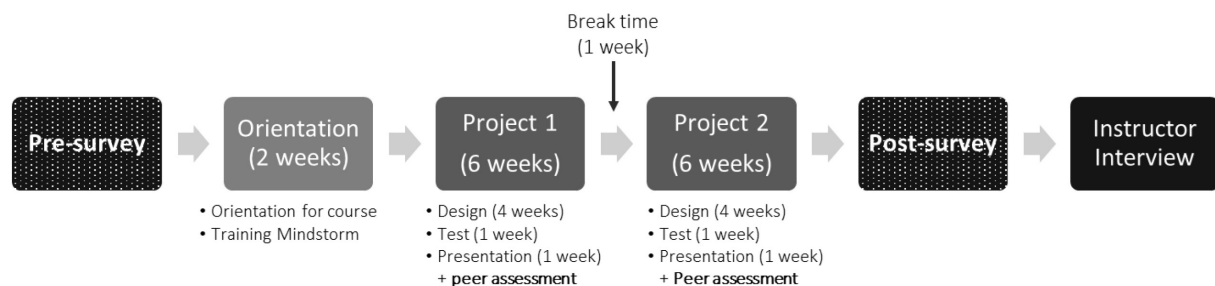


Fig. 1. Research procedure.

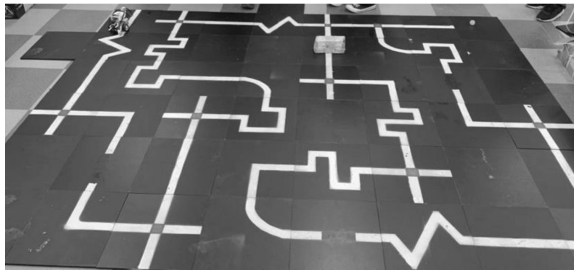


Fig. 2. Line map with obstacle unit for project 2 test

left turn red mark. In Project 2, an obstacle unit was added in order to increase the task level. Students were able to create maps by connecting line map units, so they were able to repeatedly optimize the line tracer design in new situations. The instructor facilitated the design and prototyping process of each team.

Next, in the test stage, each team measured the performance of the prototype using the test map provided by the instructor. The performance score was calculated based on the number of units driven on the map. A total of 3 test opportunities were provided to each team, and the highest record was recognized as the actual performance. Students were able to check the problem by observing each team's line tracing process.

Finally, in the presentation stage, each team presented their program design, analysis of actual performance, and improvement plan (project 1) and results (project 2) for 8 minutes to the entire class. After the presentation, it was evaluated by their colleagues for 3 minutes. Students individually responded to online worksheets developed by Google Forms using mobile devices for peer assessment. As follow as Table 1, it required students to evaluate other teams' knowledge and skills, problem-solving, creativity, and communication on a 5-point scale, and write text comments on their strengths and improvement areas. Anonymized results of peer assessment were distributed to each team the day after the presentation. Each team was asked to use the assessment results of Project 1 to improve the prototype in Project 2 and share the results during the next presentation.

3.3 Data Collection

For this study, pre- and post-surveys, peer assessment and instructor's interview were collected. First, the survey was conducted online during the first week of the course and one week after the end of the course in order to confirm the effectiveness of the engineering design course using peer assessment. Pre- and post-surveys were developed using Google Forms to measure computational thinking, creative problem solving, and collective efficacy. Computational thinking, creative problem solving, and collective efficacy were used as indicators to ensure that the core competencies required by engineers have been enhanced. All multiple-choice items were developed using a 5-point rating scale (1 = strongly disagree ~ 5 = strongly agree).

For computational thinking, the items developed by Brennan and Resnick [35] were modified to fit the course context and translated into Korean. It comprised six items on computational concepts (e.g., I can program for a line tracer to move by using sensors), four items on computational practices (e.g., I can program for a line tracer by dividing a big and difficult problem into smaller and easy problems), and four items on computational perspectives (e.g., I can ask questions and find answers about why a line tracer move this way). Reliability was high (Cronbach's $\alpha = 0.80 \sim 0.89$). Items developed by Cho and their colleagues [36] were modified to measure creative problem-solving. It comprises divergent thinking (e.g., I generate many and varied ideas that can solve problems), critical thinking (e.g., I can judge whether what other people are saying is right or wrong), and motivation (e.g., I try not to give up easily even when it is difficult and difficult, and I try to do it to the end). Each variable consisted of five items. Cronbach's α ranged from 0.85 to 0.90. Collective efficacy was measured by 21 items (e.g., I can organize team members to complete the task within the given time) developed by Alavi and McCormick [37] modified according to course context and translated in Korean. Cronbach's α was 0.97. Additionally, nine items were included in the post-survey to measure learners' perceptions on peer assessment. There were seven multiple-choice items, and two

Table 1. Peer assessment worksheets

Category	Prompts
Knowledge and skills	<ul style="list-style-type: none"> The team understood the basic concepts of programming and used the functions of Mindstorm EV3.
Problem-solving	<ul style="list-style-type: none"> The team specifically identified the engineering problem to be solved and sought a feasible solution.
Creativity	<ul style="list-style-type: none"> The engineering problems and solutions that the team discovered were creative.
Communication	<ul style="list-style-type: none"> Through the presentation of the team, I was able to effectively understand what kind of design improvement plan the team had.
Comments	<ul style="list-style-type: none"> What did you like about the team's design and presentations? What could be improved in the team's design and presentations?

essay questions that required students to describe the benefits and challenges of peer assessment during the course.

Peer assessment results written in online worksheets for project 1 and project 2 were collected. After the end of the semester, a semi-structured interview was conducted face-to-face with the instructor for 30 minutes. Questions were asked about the overall impression of the class, and the strengths and improvement areas related to peer evaluation.

3.4 Data Analysis

A paired t-test was conducted to investigate the effectiveness of the engineering design course using peer assessment. By comparing the results of the pre- and post-surveys measured before and after the course start and the end of the course, we checked the differences in learners' computational thinking, creative problem solving, and collective efficacy.

To identify students' perceptions of peer assessment, the researchers conducted descriptive statistics analysis on the nine items included in the post-survey. For the open-ended questions about the benefits and challenges of peer assessment, a thematic analysis was performed [38]. The second author read through the open-ended responses and generated initial codes inductively. Then, the second author searched for potential themes across the codes. The themes were reviewed and refined by the first and the second authors through discussion. Data from the semi-structured interview with the instructor also went through the same process for a thematic analysis.

4. Results

4.1 Effect of Engineering Design Course using Peer Assessment

The paired t-test was conducted to investigate how students' computational thinking, creative problem-solving, and collective efficacy changed before and after the course. As shown as Table 2, all three sub-variables of computational thinking

(computational concept, computational practice, and computational perspectives) significantly improved ($ps < 0.001$). The sub-variables of creative problem-solving, divergent thinking ($p < 0.001$), critical thinking ($p = 0.003$), and motivation ($p = 0.027$), all showed statistically significant improvement. Collective efficacy also significantly improved ($p = 0.044$).

4.2 Students' Perceptions about the Peer Assessment Activity

According to the questionnaire responses ($N = 36$) as shown in Table 3, most of the students (91%, $n = 33$) responded that the peer assessment activity was helpful in identifying improvement areas in their algorithms, 86% ($n = 31$) found it to be helpful in grasping diverse ideas in a short period of time, and 81% ($n = 29$) found it to be helpful in identifying engineering problems and devising creative solutions. 91% ($n = 33$) of the students responded that peer assessment was helpful in enhancing presentation and communication skills. 86% ($n = 31$) answered that the peer assessment was helpful in collaborating with classmates to program the robot and grasp diverse ideas quickly. However, a comparatively less percentage of students (69%, $n = 25$) responded that the peer assessment piqued their interest in engineering design. The same percentage of students found the peer assessment enjoyable. Taken together, although many students perceived the benefits of peer assessment in terms of improving their knowledge and skills, relatively fewer students found it enjoyable or aroused their interests in engineering design.

A thematic analysis of the written responses of students revealed several advantages of peer assessment in engineering design education. First, peer assessment helped students improve their critical thinking and problem solving skills. Students reported that the peer assessment process allowed them to think more critically about their own work and the work of their peers. By assessing peers' algorithms, they were able to reflect on their own learning and progress. As for receiving feedback,

Table 2. Results of paired *t*-test

Variables		Pre		Post		<i>t</i>	<i>p</i>
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Computational thinking	Computational concept	3.63	0.76	4.29	0.53	5.79	0.000
	Computational practice	3.53	0.82	4.20	0.53	5.64	0.000
	Computational perspectives	3.68	0.80	4.30	0.47	5.25	0.000
Creative problem solving	Divergent thinking	3.27	0.57	3.73	0.57	4.26	0.000
	Critical thinking	3.88	0.64	4.19	0.46	3.15	0.003
	Motivation	3.88	0.67	4.13	0.56	2.30	0.027
Collective efficacy		4.08	0.62	4.29	0.49	2.08	0.044

Table 3. Results of a Questionnaire on Students' Perceptions of Peer Assessment ($N = 36$)

Category	Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean (SD)	
Knowledge	The peer assessment was helpful in identifying areas that needed to be fixed.	0	1 (3%)	2 (6%)	17 (47%)	16 (44%)	4.33 (0.72)	4.17 (0.73)
	The peer assessment was helpful in grasping diverse ideas in a short period of time.	0	1 (3%)	4 (11%)	17 (47%)	14 (39%)	4.22 (0.76)	
	The peer assessment was helpful in identifying engineering problems and devising creative solutions.	0	1 (3%)	6 (17%)	11 (31%)	18 (50%)	4.28 (0.85)	
Skill	The peer assessment was helpful in enhancing presenting and communication skills.	0	1 (3%)	2 (6%)	16 (44%)	17 (47%)	4.36 (0.72)	
	The peer assessment was helpful in collaborating with my classmates to program the robot.	0	2 (6%)	3 (8%)	13 (36%)	18 (50%)	4.31 (0.86)	
Attitude	The peer assessment piqued my interest in engineering design.	0	3 (8%)	8 (22%)	13 (36%)	12 (33%)	3.94 (0.95)	
	The peer assessment was enjoyable.	1 (3%)	3 (8%)	7 (19%)	17 (47%)	8 (22%)	3.78 (0.99)	

students also stated that the peer feedback offered new perspectives on their group's coding algorithms.

"Peer feedback was beneficial in that it helped us to identify areas for improvement in our group, which we could not have identified on our own."

"I was able to evaluate my work more objectively while assessing the work of other groups."

Second, peer assessment helped students cultivate an engineering mindset through communication and collaboration among students. A student even mentioned that the overall process of peer assessment taught them the value of an engineer's mindset of accepting feedback and adopting it for improving design.

"I learned that accepting others' ideas to achieve better outcomes is a very important attitude for engineering students."

Finally, Peer assessment was useful in improving students' motivation and engagement. Students reported that the peer assessment activity was motivating and engaging, as it provided them with an opportunity to give and receive feedback. For example, students were able to focus better on their classmates' presentations in order to provide them with feedback.

"Positive comments from my peers also made me feel fulfilled."

"I was more motivated to pay attention to the presentations."

The challenges of the peer assessment activity were also identified in terms of the structure of activities and the quality of feedback. First, students mentioned insufficient time for peer assessment. During

one period (2 hours), each of the 11 teams presented their prototype and performance for 8 minutes, and the following 3 minutes were spent on evaluating the work. Students pointed out the insufficient time for providing comments.

"Due to time constraints, I could not fully put down my ideas."

"I would like more time to evaluate."

Second, the format of the peer assessment was found to be inadequate. Students suggested adding more assessment criteria so that they may review their peers' work on a broader range of aspects, including the rationale for evaluation and the attitudes of presenters.

"I would like to describe my rationale for assessment."

"It would be great if I could evaluate the presenters' attitudes such as their voice in addition to the content of the presentation."

Additionally, due to the survey format of evaluation, students mentioned the difficulties with providing consistent feedback. Students were asked to complete a Google survey form for each group's work right after their presentation. The early presenting groups were more likely to obtain unreliable scores because there were few groups to compare their work with. Once the survey form was submitted, the evaluation could not be revised.

"As the presentation and evaluation were done concurrently, the early presenting groups may have received an unreliable score because there was no group to compare with them when they were assessed. Since it was hard to revise an evaluation once it was completed, a paper version of evaluation form would have worked better."

Third, students expressed concerns about their own and their peers' abilities as assessors. Some students recognized the needs to improve their own assessment skills. They stated that because of their limited understanding of the design activity, they had difficulty with evaluating classmates' work. Several students proposed that the instructor provide a lesson on basic functions of programming at the beginning of the semester and/or on the overall designs as a wrap-up after all the presentations are finished.

"I would like the instructor's explanation after all the presentations have concluded. To be honest, I still don't fully understand the design aspects even after I wrote the codes myself. Thus, even though I wanted to give a thorough evaluation, I found it challenging to do so due to the lack of my understanding."

They also commented on the quality of peer feedback they received. Some feedback was too brief and not detailed enough, while others were overly harsh and judgmental. One student suggested the instructor's intervention to provide guidance in applying feedback.

"A couple of the feedback was too brief and lacked depth, and several peers made disrespectful comments given anonymity."

"Since students might not be able to or not want to apply their peer feedback, the instructor may be able to review each group's work and provide further guidance with selected feedback, which I believe would have led to better results."

Some students raised concerns about the fairness of peer assessment due to the course's grading system. They suspected that students may deliberately give poor scores to others, considering that they were evaluated on a curve.

"Because the course is graded on a curve, students are likely to intentionally underrate one another."

4.3 Instructor's Perceptions about the Peer Assessment Activity

The instructor found the benefits of the peer assessment activity. First, he stated that students received practical advice from their peers because they were given the same problem to solve. As the students had gone through trials and errors to tackle the same block coding task using Mindstorm EV3, they were able to offer practical and specific comments on other groups' design based on their experiences, which the instructor had not been able to consider.

"I believe the peer assessment was effective because the competing groups who worked on the same task assessed one another. Since they have thought over the same problem, they were able to offer more practical and relatable comments. . . . Students who used the tool throughout the semester will likely know more about its practical details than the instructor

would do. Thus, one of the key advantages of peer assessment is that experienced students are able to exchange comments with each other."

Second, the instructor indicated that the peer assessment activity was helpful in facilitating interactions among the students by providing a communication opportunity not just within their respective group but also among the groups. The instructor considered communication skills as one of the essential competencies for engineers and put an emphasis on providing students with relevant experiences rather than specific subject matter knowledge.

"I considered this class to be different from other required courses in that it provides students with experiences rather than delivering subject matter knowledge – a series of [problem-solving] procedures, such as communicating, discussing solutions, solving problems, and even when they could not solve a problem, analyzing why they chose a certain solution, why this approach worked and why others did not, and finally present their solution. I believe, general freshmen in Korean colleges rarely have had such an experience. I don't know, but I think it must have been helpful for my students."

He also recognized the students' improved presentation skills from the mid-term presentation to the final presentation.

"As students were familiar with the 'high test score is everything' culture, they seemed less care about presentation in the mid-term. But in the final presentation, they were certainly improved in communicating their problem-solving process more in detail – how they'd chosen a certain solution by analyzing more thoroughly why it worked or did not work."

Regarding the improvement areas, first, the instructor highlighted insufficient time allocated for both presentation and peer assessment. He suspected that the shortage of time resulted in low quality peer feedback. In this regard, he considered having fewer students in a single session or making peer assessment a take-home assignment so that students can have enough time for assessment.

"If there were less students in one class, if there were only 20 students, so that there were 3 to 4, or 5 groups in a class, students would have had enough time for presentation and given more thoughtful feedback to others. If it is difficult to be changed, I would let students upload all their presentation materials [to the Learning Management System] and write comments before the next class."

Second, the instructor suggested that a peer assessment activity should be followed by a reflection activity, highlighting the importance of incorporating feedback into one's design. He indicated that the second round of peer feedback was not reflected in students' design because it was implemented after the students had already completed their final design and presentation. He explained that a

single round of peer feedback would have sufficed, or that there should have been another presentation after the second round of peer feedback.

“Is the second round of peer feedback necessary? Is it necessary to let them comment on the final presentation? I may add a third presentation so that students can incorporate the second round of peer feedback. But then, that would cut into the time for actual design. . . . Because I believe the most important part of peer feedback is using that feedback to improve one’s design, I may let students score the final presentation but not provide comments.”

5. Discussion

It is important for engineers to have the ability to systematically, creatively, and collaboratively solve engineering problems [11]. This study found that incorporating peer assessment in engineering design education can be beneficial in promoting students’ computational thinking, creative problem-solving, and collective efficacy. Both physical computing-based design tasks and peer assessment activities are expected to contribute to this positive influence. In this study, the design task in which students iteratively, systematically, and collaboratively design, test, and improve their line tracers through engineering knowledge and skills in the real world provided a direct practice opportunity to help students improve the core competencies of engineers. Previous studies have also reported that physical computing helps to improve computational thinking [13, 14], problem solving skills [15], and collaboration skills [16]. In addition, according to the social constructivist theory, students may have achieved a higher level of development in computational thinking, creative problem solving, and collective efficacy in their ZPD, which they would not have been able to achieve without interaction with peers through the peer assessment [27]. However, it is necessary to conduct a quasi-experimental study in the future to separately confirm the effect of the engineering design education with physical computing and the effect of peer assessment.

This study, instead of investigating the singular impact of peer assessment in engineering design education, explored the perceptions of students and the instructor regarding it. Both the students and the instructor perceived the benefits of peer assessment in many ways. Students and the instructor recognized the utility of peer assessment in facilitating the problem-solving process in engineering design classes. Students reported that the peer assessment was helpful in identifying and integrating various ideas and critically reflecting on their own and their peers’ designs. The result accords with previous studies, which show that peer assessment allows students to engage in mental processes

such as critical thinking, adopting a new perspective, and reflecting on their work [7–9]. The instructor felt that peers can provide relatively better practical and specific feedback based on their own experiences of solving the same design problem. This perception is also consistent with the earlier findings that it is more beneficial to receive feedback from several colleagues than a single subject expert [18, 19]. In other words, this study provides evidence that the advantages of peer evaluation reported in previous studies are consistently applied in the context of engineering design.

Another notable finding is that peer assessment can help students grow engineer’s mindset. Peer assessment required students to explain their design artifacts, understand peers’ design artifacts, give and receive useful feedback, and review and reflect the peers’ feedback. This process allowed students to realize the importance of feedback in engineering design practices. The instructor also indicated that effective communication skills are essential in engineering practices, and students’ communication skills had improved through the peer assessment activity. One of the cultural practices of the engineering community is to seek feedback from various stakeholders to improve design quality. Peer assessment activity enabled students to experience the cultural practices found in the engineering community. Students’ experience of such practices is also supported by the social constructivism, which highlights participation in socially shared activities [28, 34]. Future studies could examine peer assessment’s impact on student’s identity development as an engineer.

A few improvement areas were also identified. First, peer assessment activities should be designed with the consideration of time, tool, and reflection process. Students and the instructor commonly noted that the time allotted for peer assessment was insufficient. To address the time issue, class size can be reduced so that each group can have enough time to get feedback after their presentation. Peer assessment activities can also be implemented as a homework rather than an in-class activity so that students can have more time for providing feedback. Regarding the tool issue, students pointed out that they were not able to provide consistent feedback across the groups because the feedback could not be revised after being submitted. Therefore, rather than using a Google survey form, future class could utilize a platform specifically designed for peer assessment, where students can write and revise feedback for each group. Although peerScholar has been suggested as a useful online peer assessment tool [39], it has the limitation of being specialized for writing assignments, indicating the need for additional tool development for

engineering design. When making peer assessment a take-home assignment, online tools will be able to ensure that students are fully engaged in assessment activities anytime and anywhere. In addition, the instructor indicated that students were not given a chance to reflect on the final peer feedback. Given that the process of interpreting feedback and reflecting them back into the design is one of the key components of peer assessment, the course can be designed in a way that peer assessment activity is followed by a reflection and/or presentation activity. Prior research has highlighted that peer assessment can only be successfully implemented within a well-designed curriculum [21, 25].

Another improvement area identified was the qualifications and competencies of students as an assessor. Students and the instructor took different perspectives in this regard. Students were not confident about their own ability as an assessor due to the lack of background knowledge. They even worried that their peers might deliberately give them low grades. On the other hand, the instructor indicated that students could provide more practical and specific feedback than the instructor can give. To address the fairness issue, we could consider integrating peer feedback rather than peer assessment, by asking students to provide informational feedback rather than awarding a score [4, 24, 40]. To improve the quality of feedback of students, many approaches can be taken. It is necessary to develop and provide evaluation criteria suitable for the context of engineering design. Training sessions can also be offered in class to improve students' evaluation skills [24, 41]. Additionally, some high-quality feedback written by instructors or excellent peers can be provided as examples. Artificial intelligence technology may also be utilized to provide adaptive feedback on students' feedback, which can serve as meta-feedback.

6. Conclusion

It is important not only to deliver specific domain knowledge to students majoring in engineering but also to develop their ability to solve problems

creatively and logically by using engineering knowledge and collaborating with other experts. To this end, students should experience the process of solving engineering design tasks through iterative prototyping, reviewing various solutions in the process, and reflecting on peer feedback. Through this experience, students are expected to cultivate the core competencies required for engineers. However, for peer assessment to work effectively in the context of engineering design education, it is necessary to train students as skilled assessors. In particular, students should be trained to value the creativity of ideas or engineering logic behind a design product, in addition to evaluating its performance. Since being able to objectively measure the actual performance of a design product is a crucial component of an engineering design task, a relevant and specific guideline should be developed for peer assessment.

This study has the following limitations. First, the effect of peer assessment could not be accurately verified. As this is an exploratory study on a case of engineering design education using physical computing with peer assessment, it is necessary to control other influencing factors through quasi-experimental studies to systematically confirm the effect of peer assessment. Additionally, to examine learning outcomes, other measures than self-reported survey can be used. Second, in this study, because the design projects were conducted in groups, the results might have differed from those of peer assessment in individual learning situations. Moreover, as the characteristics of each group can affect their process and results, it is necessary to control group characteristics. Finally, given the purpose of an exploratory study, since the study sample has been selected from a single institution in Korea, the results cannot be generalized to all engineering design classes across different settings. The results might differ for students in other countries and in other college settings with different characteristics.

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Hyunkyung Lee received the BA degrees in Education from Seoul National University, Seoul, South Korea, in 2015. She also received the MA and PhD degrees in Educational Technology from Seoul National University in 2017 and 2022. She is currently an Associate Research Fellow with Korea Institute for Curriculum and Evaluation. Her current research

interests include computer-supported collaborative learning, learning analytics, personalized instructional design with learner data.

Daeun Jung received the BA in Education and MA in Educational Technology from Seoul National University. She is a doctoral candidate in the Instructional Systems & Learning Technologies program at Florida State University. Her current research examines how teenagers use social media, examining topics such as how they use it to engage in informal learning.

Hyungjin Kim received the BS, MS, and PhD degrees in electrical engineering from Seoul National University, Seoul, South Korea, in 2010, 2012, and 2017, respectively. He is currently an Assistant Professor with the Department of Electronic Engineering, Inha University, Incheon, Korea, teaching several courses on electronic circuit, device, and engineering design. His current research interests include electronic devices and engineering education.