Introducing Sustainability in Pre-K through 5th Grade (RTP)

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Abstract

Consideration of sustainable practices is increasingly important in a multitude of fields as recognized by ABET, the National Society of Professional Engineers (NSPE), the American Society of Civil Engineers and the American Academy of Environmental Engineers and Scientists (AAEES). AAEES recommends that sustainability be integrated into all engineering disciplines and ABET includes sustainability-related criteria in several programs including architectural, industrial, and mining engineering in addition to civil and environmental engineering. There have been initiatives aiming to accelerate the integration of sustainability into curriculum across all engineering disciplines. There is a need to expand this movement beyond engineering into P-12 schools. In this work, a tangram-puzzle activity was presented to preK through grade 5 teachers to introduce the paradigm shift necessary to implement sustainability practices into traditional engineering design and construction. While the activity is a fun puzzle that is simple to implement in the classroom, it integrates several valuable components including critical thinking, interdisciplinary teamwork, and innovation. Pre- and post-activity surveys (n=15) were administered. Qualitative and quantitative analysis (Wilcoxon Signed-Rank) were performed on the survey results, which included both short answer and Likert-scale data. Results indicate the majority of the teachers felt the activity improved their understanding of sustainable engineering design and was useful and important to them in their career. Further, most teachers felt that the activity would be useful and engaging for K-5 students in their learning about sustainable design. Six of 14 teachers responded that they are likely to adopt this activity in their classrooms.

Introduction

Consideration of sustainable practices is increasingly important in a multitude of fields as recognized by ABET [1], the National Society of Professional Engineers (NSPE) [2], the American Society of Civil Engineers [3] and the American Academy of Environmental Engineers and Scientists (AAEES) [4]. AAEES recommends that sustainability be integrated into all engineering disciplines [4], and ABET includes sustainability-related criteria in several programs including architectural, industrial, and mining engineering in addition to civil and environmental engineering. Engineering for One Planet (EOP) is an example of an initiative to provide instructors in higher education with resources to integrate sustainability across all engineering disciplines [5]. As educators, we are challenged to integrate sustainability understanding not only into civil engineering education but across the curriculum, within engineering practice, and beyond into K-12 schools and the general public.

Resources for integrating sustainability into K-12 education are becoming increasingly popular. The U.S. Green Building Council offers an online education platform and professional certificate program for K-12 teachers focused on sustainability [6]. Penn State University held their first K-12 Sustainability Summit in 2024 [7] and provides links to several resources for educators through their Center for Global Studies [8]. Vanderbilt University provides resources for teaching sustainability through their Center for Teaching [9]. Also, Teach for America provides PreK-12 lesson plans for teaching sustainability [10].

Ozis et al (2022) introduced a tangram-puzzle activity in the classroom of civil and environmental engineering students to introduce the paradigm shift necessary to implement sustainability practices into traditional engineering design and construction [11]. The innovative and engaging pedagogy that nurtures "thinking outside the box" is needed for all problem-solvers. This activity can be used to teach the concept of sustainability, thinking outside the box, and a paradigm shift for the affective domain [12], for students to learn the necessary attitudes, values and motivations to implement new ways of thinking, problem solving, and designing. Normalizing failure by emphasizing what FAIL stands for, "First Attempt In Learning", encouragement of trial and error, or explaining that struggle is a proof of new learning, helps students to build resilience into their educational performance early on and can help to diversify the student body pursuing Science, Technology, Engineering and Math (STEM) and help them persevere.

The activity is an easy-to-implement, hands-on activity that can be adjusted to different age groups. In this way, it engages students at various levels with sustainability in engineering. Though simple, this activity illustrates the paradigm shift necessary to engineer a sustainable world for future generations. There is a natural alignment across sustainability and teaching since both are focused on supporting future generations at their core. So, while the activity is a fun puzzle, it integrates several valuable components including critical thinking, interdisciplinary teamwork, and innovation. Because of the paradigm shift necessary to truly implement sustainable thinking in engineering, the lessons must be taught at a young age, and this is where our P-12 educators play a pivotal role.

The activity is aligned with 'Standards for Preparation and Professional Development for Teachers of Engineering' [13] by:

- introducing participants to traditional and emerging engineering practices (Standard A)
- providing an opportunity to reflect and discuss the effectiveness of the activity as not only a learning activity but also to promote a change in behavior (Standard B)
- presenting an important topic (i.e. sustainability) that should be applied across all professions and subjects (Standard C)
- engaging participants in providing feedback on how the activity could be made more effective for various age groups and how it should be integrated into curriculum (Standard D)
- providing participants with an active-learning activity proven to be effective in engineering education (Standard E).

The activity is aligned with the three dimensions of science learning as defined by Next Generation Science Standards (NGSS) [14]. The activity is focused on 1. Science and Engineering Practices by introducing the movement to go beyond traditional engineering practices and integrating sustainability practices into the design and construction processes as well as the need to diversify the team. The activity supports 2. Crosscutting Concepts because it teaches how sustainable engineering integrates environmental, social, and economic considerations into engineering design to solve not just the local problem at hand but considering the effects globally and for future generations. Finally, an aspect of the activity and discussion is how sustainable engineering is inter- and intra-disciplinary, thus supporting 3. Disciplinary Core Ideas.

In this work, the tangram-puzzle activity by Ozis et al (2022) was modified for K-5 students and presented to teachers to introduce the paradigm shift necessary to implement sustainability practices into traditional engineering design and construction. This paper presents survey results and analysis of teacher perceptions on sustainability before and after the activity. Changes in respondent perception and ability to explain sustainable engineering are assessed as well as their opinions on if the activity would be effective for K-5 students. A summary of the discussion with respondents is included describing how some teachers recommended adjusting the activity for their classroom. This work was performed under IRB STUDY23120037 and STUDY2023_00000501.

Methods

Sustainable engineering was introduced via an active learning strategy by using tangram pieces. The first step involved making a square (as what the client wants) with four pieces representing constraints in engineering design such as resources, time, budget and technology. To make the activity suitable for K-5 students, each tangram piece was labeled with an image to illustrate what it represents. Facilitators explained that this represents "Traditional Engineering." The second step was to introduce the "sustainability" tangram piece (blue corner piece with an Oak Tree Label presented in Figure 1) and ask participants to make a new square with the five pieces (solution shown in Figure 1). The instructors explained that participants need to think differently - design for global problems and for future generations. The instructors explained that "it is not easy, but it is possible; you need to think out of the box; that is how we will ensure our designs are sustainable." After giving two more minutes, participants were asked to collaborate with a neighbor to complete the square. The instructors explained "you will never work alone as an engineer; you will team up with people across disciplines and industry to achieve real sustainability. Traditional engineering is the way we always felt comfortable, but we are struggling to re-define our approach to solving current problems." The solution was shown at the end and feedback collected.

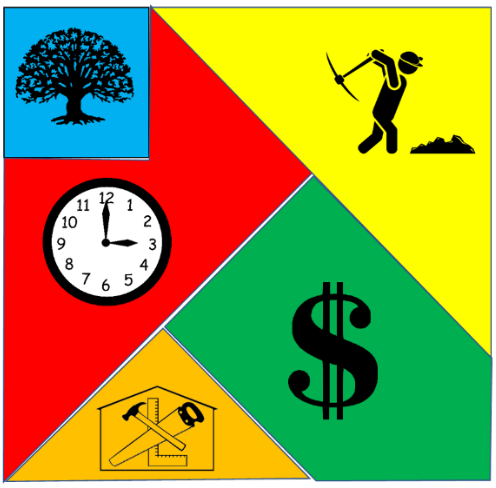

Figure 1: Tangram Puzzle Final Solution

The activity is designed for K-5 students. Therefore, Student Learning Objectives are related to lower levels of Bloom's taxonomy [15, 16] as follows:

- Explain the importance of sustainable engineering
- Compare traditional engineering to sustainable engineering
- Relate sustainability to creative thinking and teamwork in engineering design

This intervention was piloted with PreK-5 teachers as participants rather than their students to measure their learning and perceptions on the activity's value to their classroom. This work will refer to the participants of this study as teachers and respondents. Teacher learning objectives represent the highest levels of Bloom's taxonomy as follows:

- Explain and discuss sustainable engineering
- Evaluate differences between traditional engineering and sustainable engineering
- Prioritize creative thinking, teamwork, and sustainability in engineering related lessons
- Develop a lesson plan around sustainable engineering with the activity

Research questions for this study include:

- RQ1: Are PreK-5 teachers better able to explain "sustainable engineering" in their own words because of the activity?
- RQ2: Are PreK-5 teachers able to articulate a more positive perception of sustainable engineering design because of the activity?
- RQ3: Are PreK-5 teachers better able to relate sustainability with innovation in engineering design because of the activity?
- RQ4: Do PreK-5 teachers perceive the activity as being appropriate and valuable for K-5 students?

Pre- and post-surveys were administered, with 18 responses received to the pre-survey and 17 responses received to post-survey. Responses from the pre- and post-surveys were paired based on a nickname given by the respondent, resulting in 15 paired responses. As shown in Figure 2 respondents had experience teaching across Pre-K through 5th grade with 2 respondents in higher education (1 professor and 1 graduate student). Figure 3 shows that experience of respondents was evenly distributed, with a slight majority of respondents (53%) having at least 10 years of experience.

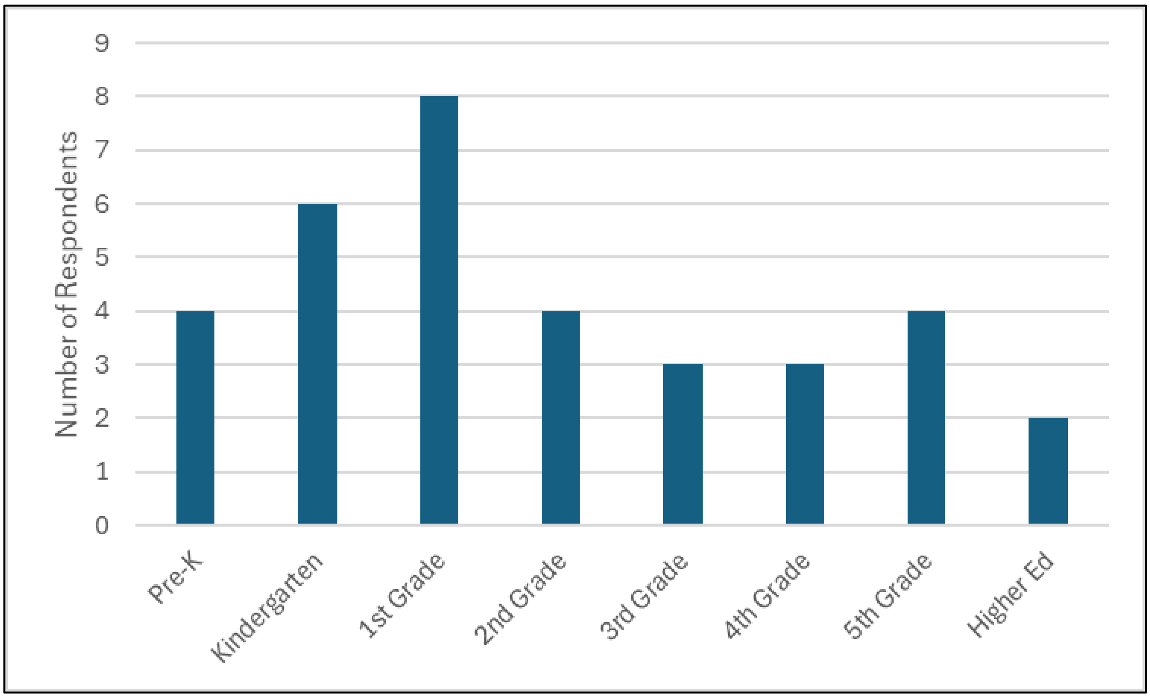

Figure 2: Teacher Role in Paired Data (n=15). Note that several respondents held more than one role, resulting in a total greater than 15.

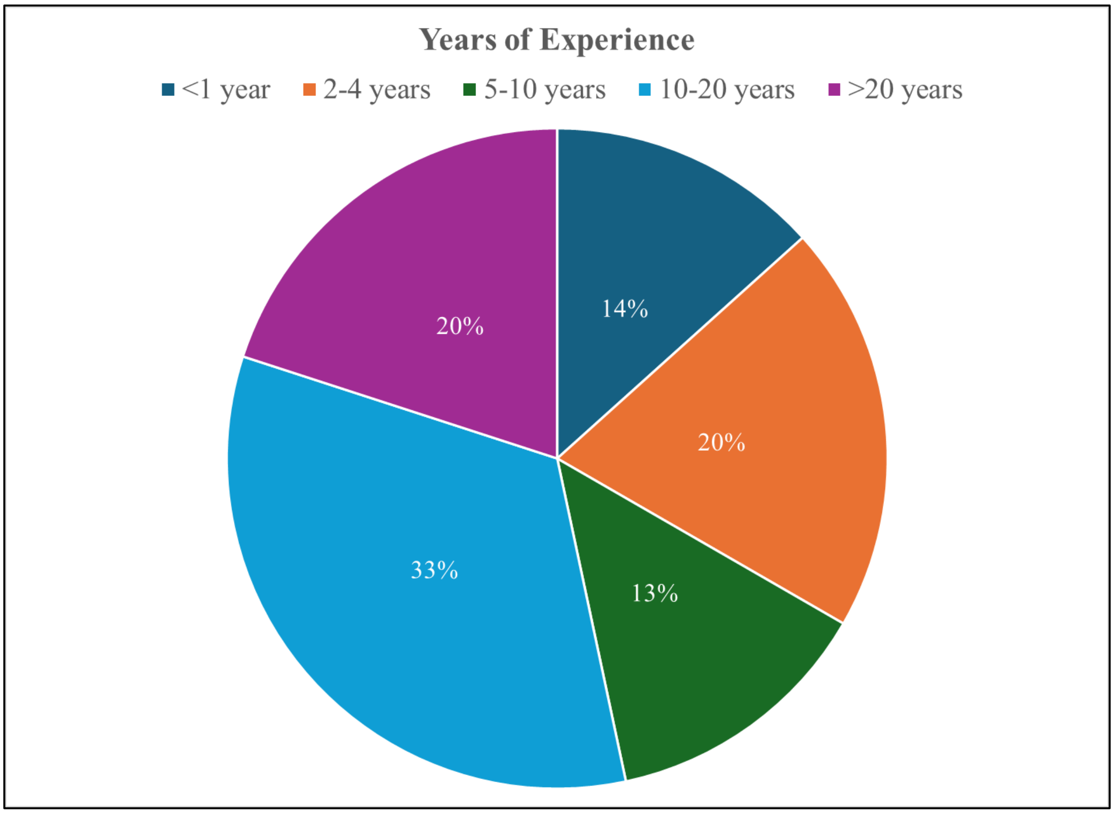

Figure 3: Years of Experience in Paired Data (n=15).

After nickname (Q1), role (Q2), and years of experience (Q3), short answer questions included the following:

- Q4: In your own words, define Sustainability
- Q5: Explain what engineers need to do to include sustainability in their practice

Paired survey questions with a seven-point Likert scale were as follows:

- Q6: Sustainability is a key component of all engineering disciplines
- Q7: It is important for engineers to implement sustainability in their designs
- Q8: It is difficult to implement sustainability in engineering design
- Q9: It is important that different viewpoints will be expressed in green engineering design
- Q10: Sustainable design requires out of the box thinking
- Q11: Sustainable design means innovation
- Q12: To implement sustainability, one needs to be innovative
- Q13: Sustainable Development is a good thing
- Q14: Studying sustainability is a waste of time
- Q15: I am open to changes in traditional ways of practicing even if it requires effort and work
- Q16: I am a passionate advocate of sustainability
- Q17: We can depend on traditional engineering practice to solve not only our current problems but also the problems of the future.

The post-survey included Q18-Q36 also with a seven-point Likert scale. Q18-27 are related to perception of learning from the activity:

- Q18: This activity improved my understanding of sustainable engineering design
- Q19: This activity was useful in promoting my learning about sustainable engineering design
- Q20: This activity helped me understand the nuanced differences between traditional engineering and sustainable engineering design
- Q21: What I learned in this activity is important for me in my career
- Q22: This activity on sustainable engineering design was interesting and engaging
- Q23: This activity motivated me to learn more about sustainable engineering design
- Q24: This activity was a waste of time
- Q25: I benefited from this Tangram piece learning activity
- Q26: If my definition of sustainability changed, I can attribute some or all of that change to this activity
- Q27: If my definition of sustainability changed, I can attribute some or all of that change to this activity (inadvertent duplicate)

Q28-Q36 are related to adaptation of the activity for K-5 classrooms:

- Q28: I am likely to adopt this activity for my classroom
- Q29: This activity could improve K-5 students' understanding of sustainable engineering design
- Q30: This activity would be useful in promoting K-5 students' learning about sustainable engineering design
- Q31: This activity could help K-5 students understand the nuanced differences between traditional engineering and sustainable engineering design
- Q32: What I learned in this activity is important for K-12 students to learn
- Q33: This activity on sustainable engineering design would be interesting and engaging for K-5 students
- Q34: This activity could motivate K-5 students to learn more about sustainable engineering design
- Q35: This activity would be a waste of time for K-5 students
- Q36: K-5 students could benefit from this Tangram piece learning activity

The Likert-scale results were analyzed by reporting ranges and medians and with the Wilcoxon Signed-Ranks test. The Wilcoxon Signed-Ranks test is a non-parametric test recommended for Likert-scale analysis. It can often be used in place of the t-test to find significant difference between paired data [17, 18].

Results

Improvement was seen in how some respondents answered the two short-answer questions (Q4 & Q5). For example, one respondent answered Q4: "In your own words, define Sustainability" in the pre-survey with "*The ability to keep something going,*" and in the post-survey with "*Thinking towards the future and how the project will impact other factors: environment, other people, etc.*" Another respondent answered Q5: "Explain what engineers need to do to include sustainability in their practice" in the pre-survey with "*rethink material use and waste*," and in the post-survey with "*include ideas about the impact to the earth and all types of people at the start of project development.*" Table 1 shows a count of relevant words in the short-answer responses for the pre- and post-surveys. There was a slight increase in use of these words in the post-survey vs the pre-survey. Words with an increase in use of two or more between pre- and post-surveys include "future", "impact", and "start".

Table 1: Word count of short answer survey questions.

	Q4. In your own words, define Sustainability.		Q5. Explain what engineers need to do to include sustainability in their practice?	
	Pre-Survey	Post-Survey	Pre-Survey	Post-Survey
future	2	6	1	3
impact	1	3	2	4
last	1	2	0	0
environment	1	1	4	3
continue	2	1	0	0
endure	1	1	0	0
needs	0	1	0	0
compromise or compromising	0	1	0	0
collaborate or collaboration	0	0	1	2
start	0	0	0	2
consequence	0	0	1	1
outside the box	0	0	0	1
keep * going	2	0	0	0
waste	1	0	1	0
consumption	1	0	0	0
efficient	1	0	0	0
reuse	1	0	0	0
innovate	0	0	1	0
social	0	0	1	0
system	0	0	1	0
recycle	0	0	1	0
global	0	0	1	0
SUM	**14**	**16**	**15**	**16**

2The Wilcoxon Signed-Ranks test indicated no significant difference between pre- and post-survey results at the alpha=0.05 level for Q6 through Q17. However, if the alpha value was increased to 0.2 (admittedly increasing the risk for a Type I error, or false positive), there was a significant difference for Q13: "Sustainable Development is a good thing." Figure 4 shows that for Q13, 13 respondents either strongly agreed or agreed in the pre-survey and two respondents more or less agreed. In the post-survey, all 15 respondents either strongly agreed or agreed.

Q7: "It is important for engineers to implement sustainability in their designs", Q14: "Studying sustainability is a waste of time", and Q17: "We can depend on traditional engineering practice to solve not only our current problems but also the problems of the future" showed a change in median between pre- and post-survey results. Q14 and Q17 are inversely worded, so these results indicate an improvement in perception for all Q7, Q14, and Q17 after the activity. No change in median was seen in the results of other questions. Medians for all positively worded questions are all above four, indicating a positive perception of sustainability before and after the activity.

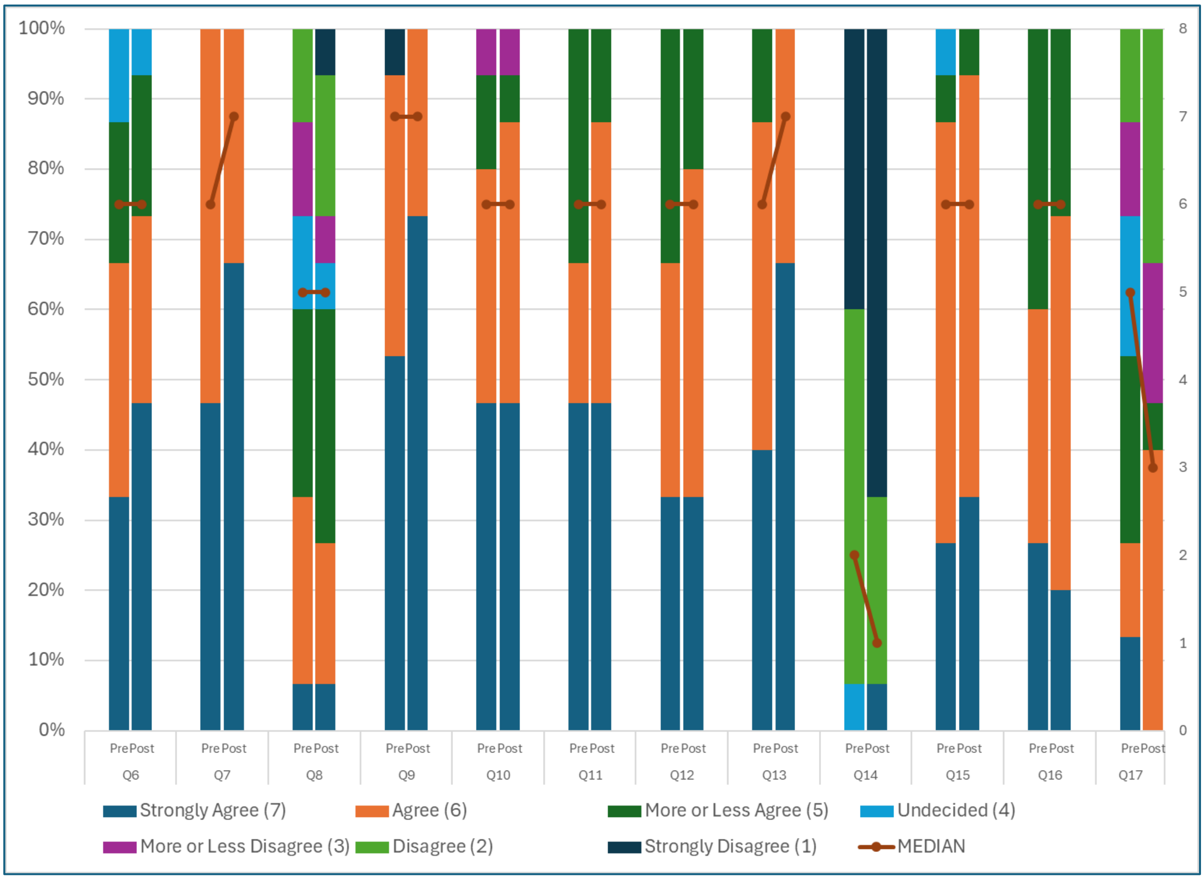

Figure 4: Pre- vs Post-Survey Responses for Paired Data (n=15).

Figure 5 and Figure 6 show that the medians of Q18 – Q36 of the post survey are all above 4, except for Q24: “This activity was a waste of time”, and Q35:“This activity would be a waste of time for K-5 students”, which were both inversely worded, and Q28: “I am likely to adopt this activity for my classroom”, and Q34: “This activity could motivate K-5 students to learn more about sustainable engineering design”, which had a median value of four (undecided). The two respondents from higher education did not answer Q28. Six of 14 teachers answered with a score higher than four, indicating they are likely to adopt this activity for their classroom. Note that Q27 was an inadvertent duplicate of Q26.

Q18-23, Q25 and Q32 scored higher than Q26-31, and Q33-36. Q18-27 (Figure 5) are generally related to the learning of the respondent (i.e. teacher), where Q28-36 (Figure 6) are focused on the respondents’ thoughts on the appropriateness of the activity for a K-5 classroom.

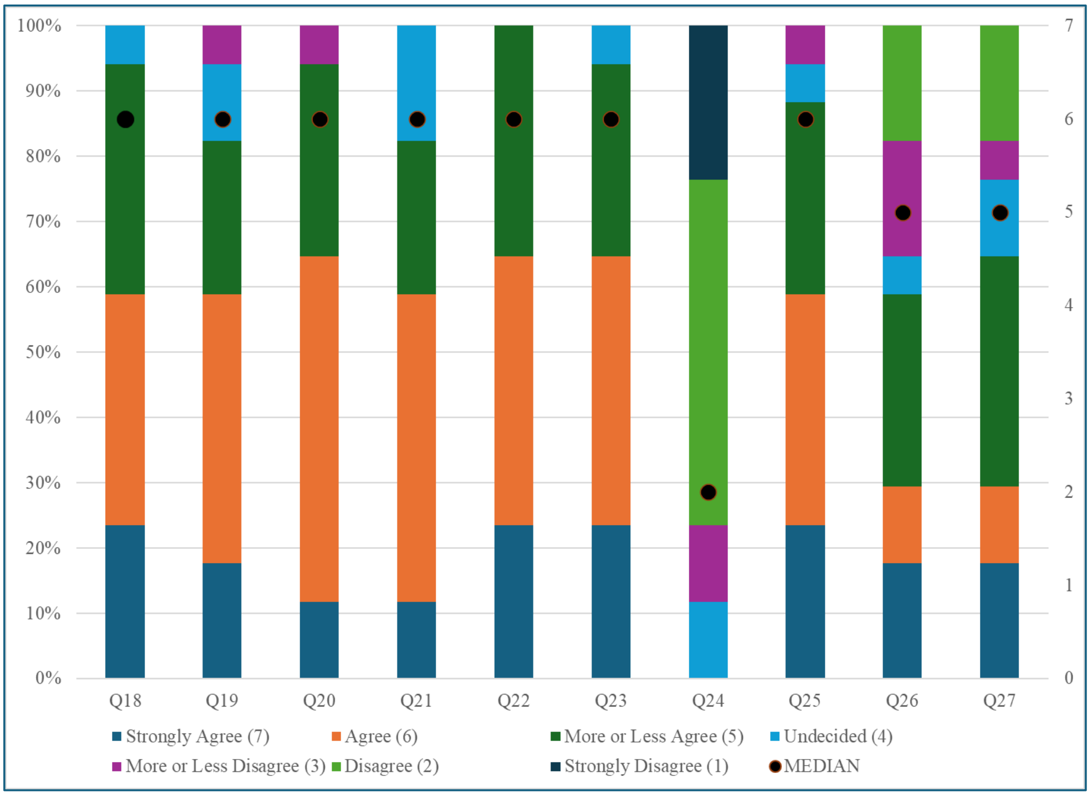

Figure 5: Post-survey responses to questions 18-27, related to perception of learning from the activity.

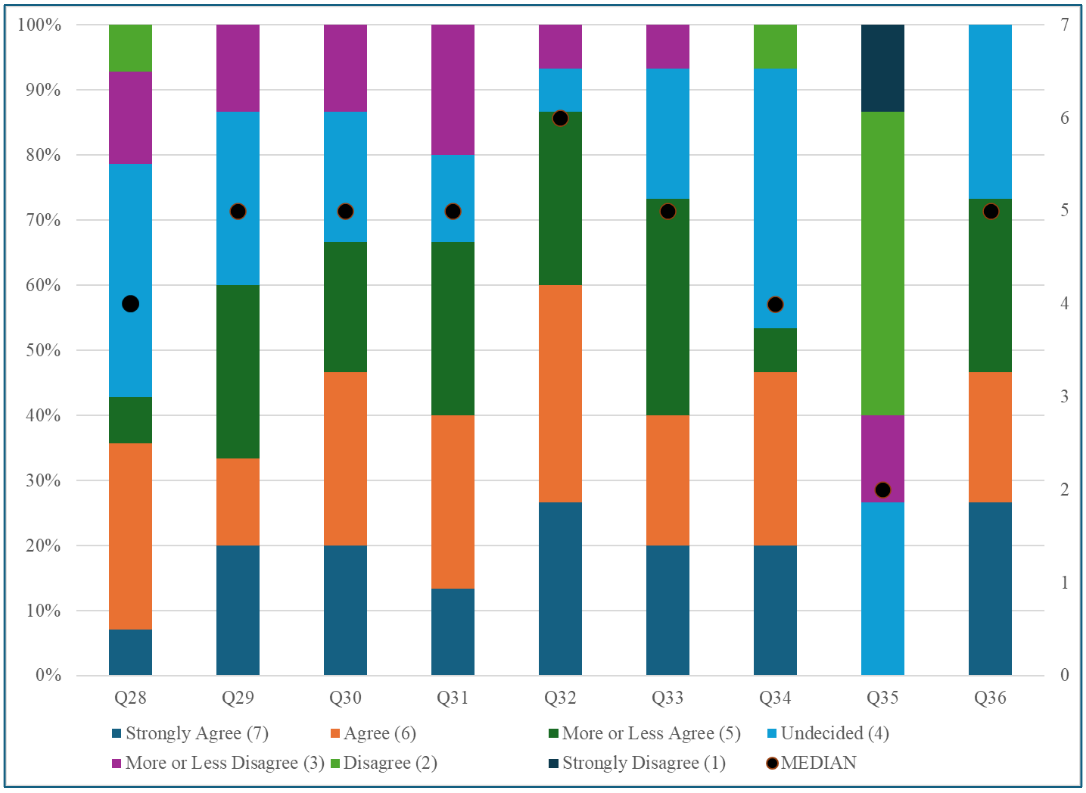

Figure 6: Post-survey responses to Questions 18-36 (n=17), related to adaptation of the activity for K-5 classrooms. Three respondents did not answer Q28 and two respondents did not answer Q29-36.

Discussion

Survey results indicate some improvement in respondents' ability to explain sustainable engineering (RQ1). Responses to Q4 indicate that more teachers mentioned the "future" and "impact" in their definitions and less focus on more basic aspects such as "waste" and "reuse." Many pre-survey responses to this question focused on resources and endurance. The following are examples of the most comprehensive definitions given in the pre-survey:

"*using resources wisely with little waste or negative impact*"

"*practices that help the environment continue producing/thriving for years to come. Not depleting resources.*"

Many post-survey responses were broader, encompassing more than just environmental aspects:

"*Thinking towards the future and how the project will impact other factors: environment, other people, etc.*"

"*Meeting the needs of people today without compromising the ability to meet the needs of people in the future.*"

While respondents began with a positive perception of sustainable engineering design, some improvement was seen after the activity (RQ2). Q6, Q7, Q13, Q14, and Q16 are related to this research question. A change in median from six (Agree) to seven (Strongly Agree) indicating improvement in perception was seen for Q7: "It is important for engineers to implement sustainability in their designs" and Q13: "Sustainable Development is a good thing" and from two (Disagree) to one (Strongly Disagree) for Q14 "Studying sustainability is a waste of time", which was inversely worded. Q6 and Q16 held a median of six (Agree) in both the pre- and post-surveys.

No change was seen in respondents' ability to relate sustainability with innovation (RQ3). Q10: "Sustainable design requires out of the box thinking", Q11: "Sustainable design means innovation", and Q12: "To implement sustainability, one needs to be innovative" are related to this research question. Medians for these three questions all stayed at six (Agree).

Most responses to Q28-Q36 were either positive (89 of 134) or undecided (32 of 134) on the value and appropriateness of the activity for K-5 students (RQ4). The medians for Q29-33 and Q36 were five (More or Less Agree) or higher.

- Q29 (Median 5): This activity could improve K-5 students' understanding of sustainable engineering design
- Q30 (Median 5): This activity would be useful in promoting K-5 students' learning about sustainable engineering design
- Q31 (Median 5): This activity could help K-5 students understand the nuanced differences between traditional engineering and sustainable engineering design
- Q32 (Median 6): What I learned in this activity is important for K-12 students to learn
- Q33 (Median 5): This activity on sustainable engineering design would be interesting and engaging for K-5 students
- Q36 (Median 5): K-5 students could benefit from this Tangram piece learning activity

The median for Q35, inversely worded as “This activity would be a waste of time for K-5 students”, was two (Disagree). The medians for Q28: “I am likely to adopt this activity for my classroom” and Q34: “This activity could motivate K-5 students to learn more about sustainable engineering design” were four (Undecided).

After the post-survey, a group discussion with participants helped to identify further perceptions on the activity. Many teachers stated that they like the kinesthetic nature of the activity, but they would modify the activity for their classroom. Some shared that they thought the activity is best suited for grades 3 and up, though it is adaptable such as doing the activity with further teacher guidance and/or some redesign.

Teacher reflections indicated that while the activity effectively shows multiple ways to approach problems and highlights sustainability as a global issue, it may be challenging for younger students. The complexity of the tangram and the abstract connection to sustainable engineering design might lead to frustration and strong emotions, especially for first graders. Although it's hands-on and engaging, the activity could benefit from more context on sustainability in engineering. Overall, participants indicated that it is a great warm-up and could benefit from a detailed explanation of sustainability.

To enhance the activity, teachers recommended incorporating notetaking and starting with fewer, larger, and sturdier pieces in a teacher-led, whole group setting. Emphasizing collaboration by encouraging table talk and partner work, using books and pictures to introduce the activity, gradually increasing puzzle difficulty without focusing on abstract concepts, simplifying the task, and connecting it to a meaningful design activity immediately after the tangram puzzle were recommended. Also, providing quick and straightforward explanations, and creating the puzzle pieces with wooden or 3D printed blocks instead of cardstock was suggested.

Some participants discussed that they thought sustainable thinking is already a standard practice, but experienced engineers feel there is still a need to better integrate sustainability into engineering practices. This is an area of future research, along with evaluating the activity with K-12 students, grade 6-12 teachers, higher education students of various majors, engineering and related professionals, and the general public.

Limitations of the study include the small sample size of 15 teachers surveyed, which can limit generalizability of our conclusions. Also, this work focused on teacher perceptions rather than students, thereby limiting measurement of the value of the activity since student learning was not assessed.

Conclusion

While the activity is not meant as a stand-alone lesson to address all aspects of sustainability, it can be an effective introductory module to engage K-5 students and introduce the concept. It was also helpful in providing K-5 teachers who do not have professional engineering education and experience, in the need for a paradigm shift to integrate sustainable thinking in design. Survey results showed improvement in K-5 teachers’ understanding and definition of sustainability from pre- to post-activity. K-5 teachers agreed that this activity can be helpful teaching sustainability to elementary students. Further discussions around this activity led to comments suggesting adaptation to more sturdy pieces instead of cardstock, and more directed guidance provided by the teachers to K-5 students to be able to make those intended connections. The majority of the participating K-5 teachers recommended this activity for grades 3 and above, as students in these grades are better able to understand the abstract connection between tangram pieces as engineering design constraints and sustainable engineering design.

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