2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33808

Student Reflections on Sustainability and Empathy: The Outcomes of a Sustainability Workshop in First-year Design Courses

Mr. Rohan Prabhu, Pennsylvania State University

Rohan Prabhu is a PhD Candidate in Mechanical Engineering at Penn State with a doctoral minor in Psychology. He holds a master's degree in Engineering Design and a bachelor's degree in Mechanical Engineering. His research interests are to study designers' use of design for additive manufacturing in their creative problem-solving process. He is also studying the development of effective educational interventions on design for additive manufacturing to encourage student learning and use of these concepts in engineering design. More about Rohan's work is available at prabhurohan.com.

Dr. Elizabeth Marie Starkey, Pennsylvania State University

Elizabeth Starkey is an Assistant Teaching Professor at Penn State. Her research focuses on creativity during the design process and building tools to facilitate learning and creativity in engineering design education.

Dr. Mohammad Alsager Alzayed, Kuwait University

Mohammad Alsager Alzayed is an Assistant Professor of Industrial and Management Systems Engineering at Kuwait University. He received his PhD in Industrial Engineering from the Pennsylvania State University in August 2020.. He received his M.S. in Industrial Engineering in 2017 and a B.S. in Industrial Engineering in 2017, all from the Pennsylvania State University. His research interests are in engineering education and human factors.

STUDENT REFLECTIONS ON SUSTAINABILITY AND EMPATHY: THE OUTCOMES OF A SUSTAINABILITY WORKSHOP IN FIRST-YEAR DESIGN COURSES

ABSTRACT

Given the growing need for sustainability in engineering, there has been an increased emphasis on introducing sustainability in the engineering design curriculum. Towards this end, several researchers and educators have proposed educational initiatives for integrating sustainable design in the engineering design curriculum, as early as in the first year of study. However, these initiatives are only as successful as students' ability to relate to the issues related to unsustainable behavior and take active measures towards these issues. Prior research has suggested the influence of empathy on designers' ability to relate to the users' needs. In the context of sustainable design, students must not only relate to the needs of the primary user but also empathize with those indirectly affected by their decisions. However, little research has explored the influence of students' trait empathy on the outcomes of sustainable design education and we aim to explore this research gap. Specifically, we introduced first-year engineering students to a two-day workshop on sustainable design approximately three-quarters of the way through their semester-long design project. At the end of the semester, students were asked to reflect on the utility of the workshop towards both, empathizing with the user, and designing sustainable solutions, in their semester-long projects. From our results, we see an increase in students' attitudes and intentions towards sustainability from before the workshop to the end of the semester. On the other hand, we see no differences in students' trait empathy. A qualitative analysis of students' reflections showed that students had a positive experience with the sustainability workshop and that they were more inclined to incorporate sustainable design practices into their project after participating in the workshop. These findings suggest the need for future work on the role of empathy development in encouraging a sustainable design mindset among engineering designers.

Keywords:

1. INTRODUCTION

As global resources head towards depletion, sustainable engineering practices have become an important topic of consideration. Several engineering domains are actively adopting sustainable practices (e.g., circular economy and lifecycle management) and a similar increase in emphasis on sustainability is observed in engineering education [1]. Researchers have also proposed educational initiatives to introduce students to sustainable design [2]–[4], with some introduced as early as in the first year of study [5]–[7]. For example, Price and Minster [6] present a three-course sequence integrating sustainability and design. Through comparison of pre- and post-course surveys, the authors demonstrate the effectiveness of the course in increasing first-year students' knowledge of and confidence in integrating sustainability into engineering design. Similarly, Ritter et al. [7] present a half-semester project on sustainability introduced as part of an introductory course on engineering design. In the project, students are asked to look at sustainable design from a systems-design lens and also asked to take into account the direct and indirect impact of their solutions on society, the environment, and the economy.

Despite the introduction of these educational initiatives, student designers' *active* adoption of sustainable design practices could be governed by their individual differences [8]–[10]. This influence of designers' individual differences is particularly underscored as the outcomes of adopting sustainable design might not often benefit the designer directly. For example, individuals in developed countries – who have access to clean drinking water 24x7 – might not directly benefit from conserving water compared to those in sub-Saharan Africa, where access to clean water is a challenge. However, individuals in developed countries might be in the position to make a significant impact on the water shortage problem. Therefore, for sustainable design education to be successful, students must be able to empathize with those suffering from sustainability-related issues, directly and indirectly [11].

The various educational interventions proposed in the literature introduce students to sustainability in engineering design; however, researchers argue that the emphasis on the social aspects of sustainability is both, lacking and often a challenge to implement [12]–[17]. Towards this end, some researchers have proposed initiatives that emphasize the social aspects of sustainability in engineering design. For example, Pappas and Kander [18] present a six-semester program on sustainable engineering design at James Madison University. One of the key aspects of their program is the emphasis on the economic, cultural, and social aspects of sustainability. While courses such as these introduce student designers to the social aspects of sustainability, there is a need to further understand how they impact student designers' ability to empathize with those suffering the ill effects of unsustainable behavior, and consequently, adopt sustainable design.

Empathy, or "the reactions of one individual to the observed experiences of another" ([19], p. 113)", has been shown to help students develop effective teamwork skills, better contextualize problems, and provide design inspiration [20]. As such, researchers in engineering education have become invested in studying empathy with more than 400 papers published on empathy from 1995 to 2018 in the ASEE annual conference proceedings [21]. In the context of engineering design, prior research has found that empathy can be impactful during the concept generation and selection stages of the design process. For example, Johnson et al. [22] found that student students' engagement in empathic design experiences helped them generate ideas of high quality, novelty, and variety. Similarly, prior work found that high team empathy, measured using the Interpersonal Reactivity Index [19], positively impacted students' generation and selection of highly unique ideas [23]. Therefore, empathy development in engineering design education could help students not only better understand users' needs, but also generate creative solutions to meet these needs.

Therefore, empathy plays an important role in engineering design, especially in determining designers' ability to successfully understand the needs of the user. While there has been an increase in research on empathy development in engineering design education, a majority of this work has focused on understanding the needs of the primary user. Although this direction of work is important, the effects of sustainable design practices often do not directly affect the primary user of the product. Moreover, few student designers could have direct experience with the ill effects of issues related to sustainability. Empathy development could play a particularly important role in designers' implementation of sustainable design practices in light of work by Kouprie and Visser [24], who suggest that designers' ability to empathize with the user and act upon this feeling is strongly influenced by their prior experiences. Designers' prior experiences

with and perceptions of issues related to sustainability could influence their ability to relate to these issues and act upon them. Therefore, for sustainable design to be impactful, students must be introduced to empathy not only as it related to the primary users of their solutions but also with those affected indirectly by their decisions. Little research has investigated this interaction between empathy and sustainability [25], especially in engineering design educational settings and our aim in this study is to explore this research gap. Specifically, we aim to investigate if students' participation in a short workshop on sustainable design relates to their reflections on sustainability and empathy in a semester-long design project. Towards this aim, we seek to explore the following research questions (RQs):

- ***RQ1: How do students' trait empathy and attitudes towards sustainability change from before participating in the workshop on sustainable design to the end of the semester?***

- ***RQ2: What were students' experiences in the sustainable design workshop and how did it influence their perceived use of empathy and sustainability concepts in their semester-long design project?***

To answer these research questions, we performed an experimental study with undergraduate students, the details of which are discussed next. We then discuss the key results from our experiment in Section 3 including the implications of our results for design education. Finally, we conclude with the limitations of our work and directions for future work in Section 4.

2. EXPERIMENTAL METHODS

To answer the RQs presented in Section 1, we performed an experimental study with first-year undergraduate students. The details of the experiment, including the metrics used to assess the outcomes, are discussed next.

2.1. Participants

The participants in our study were recruited from a first-year introductory course on Engineering Design at a large public university in the northeastern United States. A total of 27 participants consented to participate in the study and written consent was obtained through email as per IRB protocol. Of the 27 participants, 14 self-identified as male, and 8 self-identified as female, and 5 participants did not provide this information. Additionally, of the 27 participants, 21 were first-year students, one was a second-year student and 5 did not provide this information.

2.2. Procedure

The data used in our study were collected in two stages. First, a two-day workshop on sustainable design was conducted approximately three-quarters of the way through the semester. Then, students worked on their semester-long design project and completed a reflection assignment at the end of the semester. The overall procedure followed in the workshop is presented in Figure 1. We discuss the details of each of the two data collection stages next.

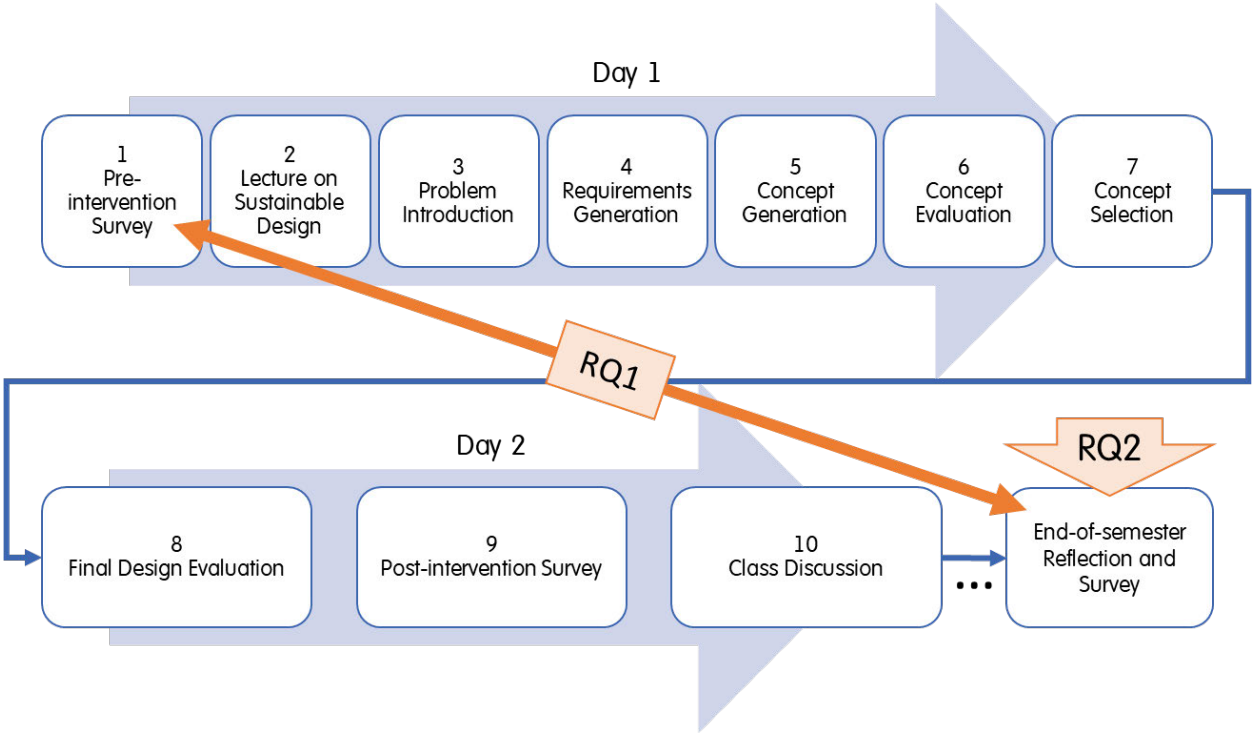

Figure 1 Overview of the experimental procedure

2.2.1. Sustainable Design Workshop

The sustainable design workshop was conducted during two class periods, with each day lasting approximately 1.5-hours and one day between the classes. Before the start of the workshop, participants completed a pre-workshop survey (details in section 2.3.1). Next, the instructor provided a lecture on sustainable design lasting for approximately 10 minutes. Participants were introduced to life cycle assessment as well as the ten sustainable design heuristics proposed by Blevis [26]: (1) disposal, (2) salvage, (3) recycle, (4) remanufacture for reuse, (5) reuse as is, (6) longevity, (7) sharing for maximal use, (8) achieving heirloom status, (9) finding wholesome alternatives, and (10) active repair of misuse. At the end of the lecture, participants were introduced to the 17 United Nations (UN) sustainable development goals (SDGs)[a] and focus was given to goal #6: Clean Water and Sanitation, due to the connection with the design problem. Next, participants were introduced to the following design problem:

> *In Sub-Saharan Africa, nearly 46 people die per 100,000 people due to diseases caused by the lack of safe water, sanitation, and hygiene (WASH) services. This is nearly four times the global average of 12 deaths per 100,000 people due to poor access to WASH services. you are tasked with designing a solution to help improve access to clean water and sanitation to Eli and others in his village.*

[a] https://sdgs.un.org/goals

In addition to the design problem, participants were given the following persona and some background information on the design problem in a one-page design prompt:

> *Eli is a 40-year-old man who lives in the Sub-Saharan African region. He lives with his wife and two teenage children. He is a farmer by profession – a low-income profession – and has received some middle-school level education. Eli lives in a small remote village with some access to electricity but no access to other technological resources (e.g., internet and cellular service). The electricity is primarily used to operate water pumps that source water from either (1) a nearby polluted river or (2) contaminated and ill-maintained wells in and around the village. Since these are the only two sources of water for Eli and his family, they are highly prone to water-borne diseases.*

Next, participants began working through the design process, starting with requirements generation. Participants were given 20 minutes to develop requirements or customer needs and create an Analytical Hierarchical Process (AHP) matrix to weigh their needs. Next, participants were given 15 minutes to come up with as many ideas as they could for their design problem. Immediately following idea generation, participants were given 15 minutes to evaluate their concepts using a Pugh chart to help guide them in selecting the best idea to move forward with. They then created a sketch of their final idea based on their concept selection and evaluated their final design for how well it met the customer needs. In addition to rating their idea for their customer needs, participants also rated how well their idea incorporated the ten sustainable design heuristics. Lastly, the participants rated the percent overlap of their customer needs with the sustainable design heuristics. After the workshop (end of day 2), participants completed a post-workshop survey.

2.2.2. Semester-long Design Project

Over the course of the semester students completed a design project in groups of 3 or 4 where they were given the following design prompt:

> *As the way we shop changes, so do our needs, and vice versa—giving us a fresh opportunity to rethink the grocery shopping experience. Therefore, your design project as a part of *Class name removed for review* asks you to address the needs of grocery store stakeholders (e.g., shoppers, workers, owners, etc.) for the world of today and tomorrow.*

Students spent approximately 20 class periods working on their design project over the course of the semester, with each class period lasting 1 hour and 50 minutes. Students completed 3+ iterations of the design process before presenting their final designs to the instructor at the end of the semester. The five-step design thinking process (i.e., empathize, define, ideate, prototype, and test[b]) was used as a guide for students as they worked on their projects.

The sustainability workshop was introduced approximately ¾ of the way through the semester-long design project when students had just completed their second iteration prototype. At the end of the semester, upon completion of their semester-long project, participants completed an end of

---

[b] https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

the semester survey with the same items as the pre-workshop survey. Participants were also asked to reflect on the following questions:

1. Summarize your experiences with the sustainability workshop.
2. How did the sustainability workshop impact your final design outcomes in your grocery experience project?
3. The first stage of the design process is to empathize with the user. Did the sustainability workshop impact your ability to empathize with your user for your grocery experience project? Describe why or why not.
4. How did you incorporate concepts of lifecycle assessment in your grocery experience project?

The participants' responses to the end-of-semester surveys were compared to the pre-workshop responses to answer RQ1. Additionally, their reflection essays were qualitatively analyzed to answer RQ2.

2.3. Metrics and Coding Schemes

The data collected from the experiment were assessed using the metrics discussed next.

2.3.1. Pre-workshop Survey

Before the workshop, participants were asked to complete a pre-workshop survey in which we collected a baseline of their trait empathy and their attitudes towards sustainability. The specific measures used to capture these two constructs are discussed next.

1. Trait empathy: The students' trait empathy was measured using the Interpersonal Reactivity Index (IRI) [19]. The IRI measures individuals' trait empathy on four components: (1) perspective taking, (2) fantasy, (3) empathic concern, and (4) personal distress. The IRI was used to measure trait empathy because it is one of the few instruments that assess both the cognitive and affective components of empathy. Previous research has discussed that both cognitive and affective components of empathy are needed to help designers better understand the needs of the user [24], [27]. Additionally, the IRI has been used in several studies in engineering design research to measure designers', and especially student designers' trait empathy (e.g., see [28]–[30]).

2. Attitudes towards Sustainability: The 25-item survey used in [31] was used to measure students' attitudes towards sustainability. The survey measures students' attitudes towards sustainability on three components: (1) beliefs (six items), (2) attitudes (thirteen items), and (3) intentions (six items). This measure was chosen to capture both, students' perceptions about the need for sustainable action (i.e., beliefs and attitudes), as well as their tendency to act upon this need (i.e., intentions).

The internal consistency of the measures was established through an observed Cronbach's α [32] > 0.7 for each component of both parts of the survey.

2.3.2. Coding Scheme Used to Analyze Student Reflections

Students' responses to the reflection essays (see Section 2.2.2) were coded through an abductive content analysis approach [33]. Specifically, this coding scheme allowed us to take into account the prior literature on trait empathy and sustainability while also being responsive to the nature of the data. The complete coding scheme used is presented in the Appendix. First, 20% of the data was coded on the sentence level by two raters (one Assistant Professor of Industrial Engineering and one Assistant Professor of Engineering Design) using Microsoft Excel. Upon observing acceptable inter-rater reliability [34] (Cohen's Kappa = 0.76), one of the raters coded the remaining data.

3. RESULTS AND IMPLICATIONS FOR DESIGN EDUCATION

The data collected from the experiment were analyzed using qualitative and quantitative techniques and the results of the analyses, along with their implications on design education are presented next.

3.1. How do students' trait empathy and attitudes towards sustainability change from before participating in the workshop on sustainable design to the end of the semester?

First, the students' responses to the surveys collected before the workshop and at the end of the semester were compared to assess changes in their trait empathy and attitudes towards sustainability. First, we performed paired-samples t-tests between the total pre-intervention and end of semester scores on each of the four components of the IRI – i.e., (1) perspective taking, (2) fantasy, (3) empathic concern, and (4) personal distress. From the results summarized in Table 1, we see that students reported no significant changes in their trait empathy scores from before participating in the workshop to the end of the semester.

Table 1 Comparing students' trait empathy from before the workshop to the end of the semester

Empathy Component	t	*p*	Pre-workshop	End of Semester
Perspective Taking	-0.33	0.74	24.63 (4.32)	24.91 (4.65)
Fantasy	1.39	0.18	25.95 (4.10)	25.09 (3.96)
Empathic Concern	0.91	0.37	26.27 (3.76)	25.55 (3.83)
Personal Distress	0.77	0.45	19.43 (3.64)	19.00 (3.89)
Bold indicates significantly higher scores at $p < 0.05$				

A similar analysis was performed with the participants' responses to the attitudes towards sustainability scale. Specifically, participants' total scores on the three components of the scale, i.e., (1) beliefs, (2) attitudes, and (3) intentions, were compared from before the workshop to the end of the semester using paired-samples t-tests. From the results, summarized in Table 2, we see that students reported a significant increase in their attitudes and intentions towards sustainable action from before the workshop to the end of the semester.

Table 2 Comparing students' attitudes towards sustainability from before the workshop to the end of the semester

Attitude Component	t	*p*	Pre-workshop	End of Semester
Beliefs	0.644	0.528	21.11 (4.91)	20.79 (4.08)
Attitudes	-1.852	0.081	41.67 (8.98)	**43.72 (10.10)**
Intentions	-4.038	0.001	19.44 (4.18)	**21.39 (4.53)**
Bold indicates significantly higher scores ($p < 0.1$)				

These findings suggest that the students' trait empathy is a relatively stable construct when compared from before the workshop to the end of the semester. Moreover, the lack of changes in students' trait empathy from before the workshop to the end of the semester could suggest that participating in the workshop does not increase their trait empathy. However, this result could be attributed to the high level of trait empathy observed pre-workshop. Specifically, as seen in Table 1, students reported relatively higher levels of perspective-taking, fantasy, and empathic concerns pre-workshop compared to the scale means of 21. This high level of pre-workshop score could have limited the ability of the workshop to increase students' trait empathy.

On the other hand, the increase in students' attitudes and intentions towards sustainability is a positive outcome. The increase in students' intentions towards sustainability is a particularly interesting finding as it suggests that participating in the workshop could encourage students to generally, act upon their beliefs about sustainability. This increased tendency to act sustainably could, in turn, result in them actively utilizing their knowledge of sustainable design in the engineering design process.

3.2. What were students' experiences in the sustainable design workshop and how did it influence their perceived use of empathy and sustainability concepts in their semester-long design project?

The second research question was devised to evaluate students' experiences in the sustainable design workshop and how it influenced their perceived use of empathy and sustainability concepts in their semester-long design project. To address this research question, students' reflection essays collected at the end of the semester were coded using an abductive content analysis approach [33] (see Appendix for complete coding scheme).

From the results of the content analysis, we see that a majority of the students (n = 19) reported positive experiences with the workshop on sustainable design, two students reported negative experiences, and three students discussed the impact of the workshop but did not express their feelings on the impact (indifferent). One student did not discuss their experiences. Importantly, the two students who cited their negative experiences of the workshop also discussed positive aspects of their experience. For example, participant 2 mentioned "One of the more difficult aspects of [the workshop] was the restrictive time limit that was required…" but followed up with "the sustainability project played a great role in opening my team's eyes to a need that we had not focused much on… sustainability"

Additionally, several students focused on the utility of the workshop with respect to the different design stages and their semester-long project. As seen in Figure 2, most of the students reported on the influence of the workshop on the stages of (1) empathizing with the user (n = 20), (2) problem definition (n = 17), and (3) ideation (n = 14). This result indicates that students perceived the utility of the workshop in supporting the early stages of the design process or at the beginning of each iteration of the design process.

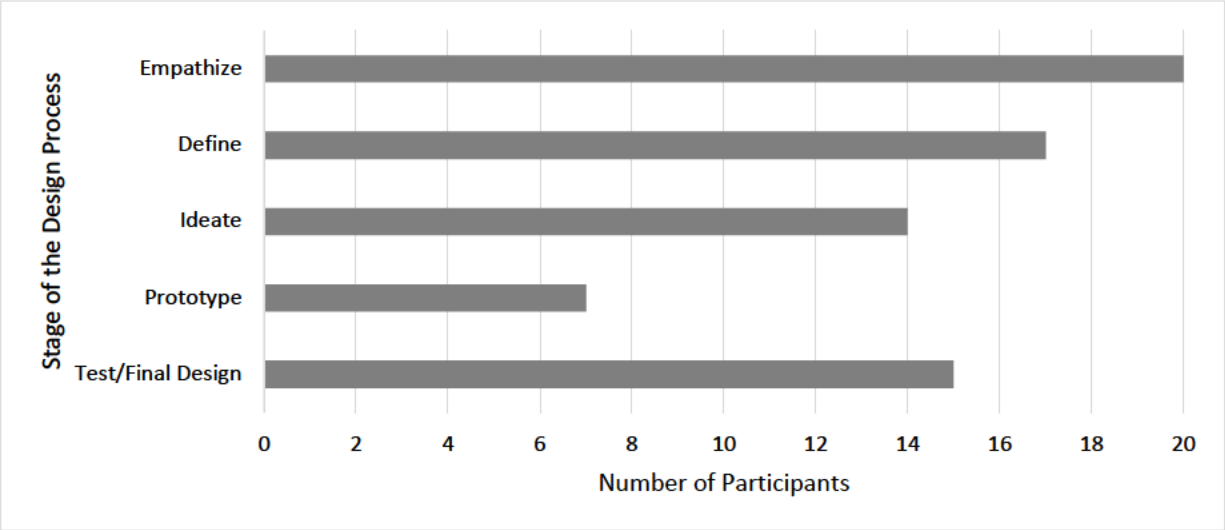

Figure 2 Number of participants that discussed each of the design stages

Furthermore, we see that a majority of the students (n = 13) believed that the workshop had a positive impact on their ability to empathize with the end-user and five students reported that the workshop had no impact on their ability to empathize. Notably, no students mentioned that the workshop had a negative impact on their ability to empathize with the user. In order to get a deeper understanding of the empathic tendencies discussed by students, we coded for students' discussion of the four components of trait empathy, i.e., perspective-taking, personal distress, fantasy, and empathic concern. Results show that students only reflected on their perspective-taking (n = 7) and empathic concern (n = 7) tendencies, and not their fantasy or personal distress tendencies. For instance, participant 7 mentioned, "this challenge helped me get comfortable with having empathy and placing myself in another's situation".

These results resonate with prior research that claims that perspective-taking tendencies are relevant in engineering [28], specifically in human-centered design contexts [35], since it can help students to develop a deeper understanding of the needs of users that are different from themselves. These results also indicate the potential effectiveness of a sustainability workshop to trigger students' empathy and call for further investigations that empirically assess the impact of sustainable design workshops on students' trait empathy.

In terms of students' attitudes towards sustainability, we see that students discussed their beliefs, attitudes, and intentions on sustainability, with 12 students discussing their beliefs on sustainability. For example, participant 9 mentioned, "This activity made me look deeper into what sustainability really means especially on a larger scale." Meanwhile, 16 students reflected on their attitudes towards sustainability, while 18 students indicated their intentions towards sustainable actions. For example, participant 10 said, "Sustainability was not primarily considered during our grocery experience project, and we in fact did not consider it at all until [we were] prompted to."

During the workshop, students were introduced to ten sustainable design heuristics (see Section 2.2.1). Notably, almost all students (n = 22) discussed the use of at least one sustainable design heuristic, indicating the potential effectiveness of the lecture on sustainability in encouraging students to use the heuristics in their final projects. Of the ten heuristics, students mentioned their use of almost all of the heuristics in the design challenge, as shown in Figure 3. Only the heuristic of salvaging existing resources was not mentioned by any participant.

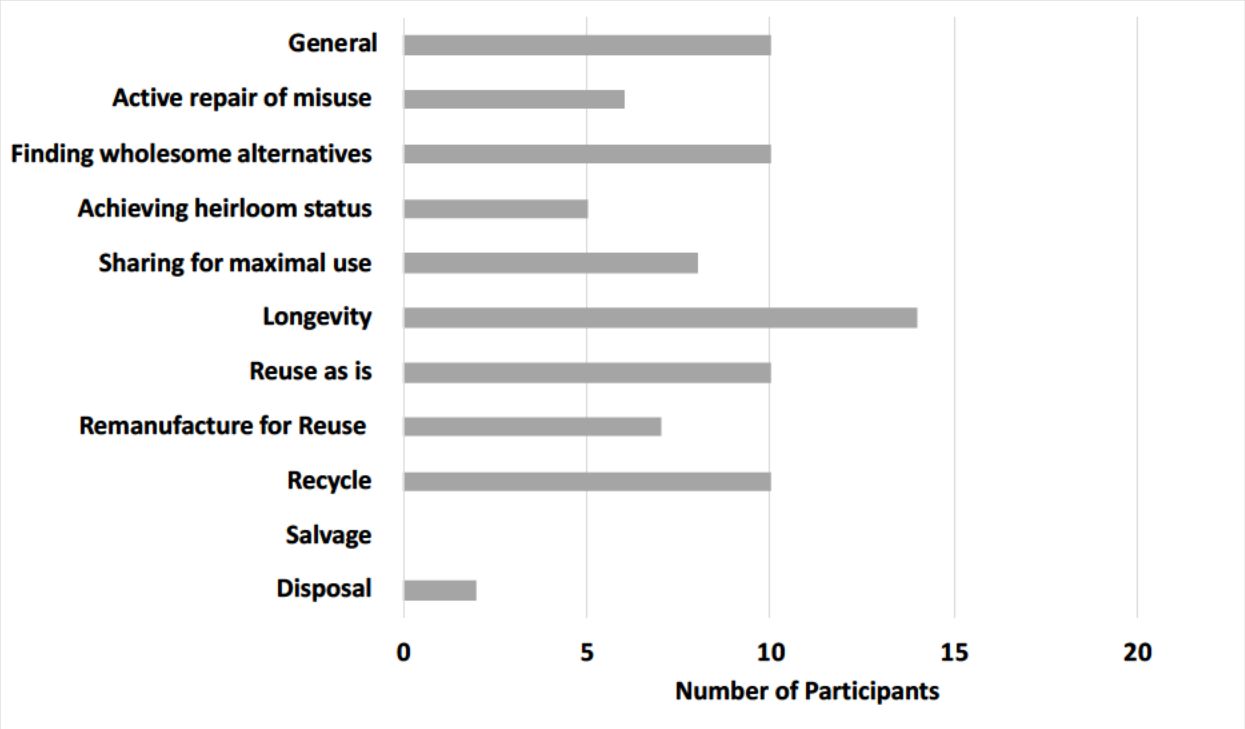

Figure 3 Participants' discussion of the sustainability heuristics in the reflection essays

3.3. Implications for Engineering Design Classrooms

Taken together, the results from these research questions indicate that participating in the sustainable design workshop had a positive influence on the students. This positive influence was

observed both, through increases in their attitudes and intentions towards sustainability, as well as through the perceived utility of and positive experience with the workshop. Moreover, students reported that they actively incorporated sustainable design practices into their semester-long project after participating in the workshop and were better able to empathize with the user. We discuss the implications of these results in the remainder of this section.

First, we see that most students reported that participating in the workshop positively influenced them in the empathize stage of the design process. Since the workshop was conducted in the last quarter of the semester, this result indicates that the workshop may have redirected students' focus to the empathize stage during the later stages of the design process. For example, one participant stated "the sustainability design challenge helped us to reflect on the goals that we made at the beginning of the process. This allowed us to reconnect with the user needs that may have been lost a little during the process or not considered in the first place" (Participant 9). Another participant stated "we were so focused on the cost and making it as efficient as possible, but at times we forgot we were not making the cart for ourselves, but for others. The challenge allowed just to refocus and really focus on what the user wanted in the cart from the feedback and interviews." While we did not see an increase in trait empathy, these reflections show a renewed sense of importance toward empathy in the semester-long project after the sustainable design workshop. This result supports the idea that although trait empathy remained stable in the period we tested, a sustainable design workshop can help students refocus on empathizing with the users.

On the other hand, we also see that several participants reported that the workshop did not help them connect with the users in their semester-long projects. They reported that this lack of impact was because they already were able to connect with grocery store users since they are grocery store users, themselves. For example, Participant 6 said "The sustainability design challenge did not help me empathize with grocery shoppers because I am a grocery shopper. I had no problem putting myself in the shopper's shoes because I have had the same problems as them many times before." This is an interesting finding as it suggests that students possibly find it easier to relate to issues that they themselves could face, in comparison to issues and situations they haven't faced. This finding corroborates prior research suggesting that individuals are more likely to act upon situations they have/could themselves face, compared to those primarily faced by others [36]–[38].

Finally, we see that participating in the workshop not only brought new focus to the empathize stage of the design process, but it also brought a focus on sustainability. Moreover, these two aspects were linked in their discussions with sustainability often being cited as a customer need. For example, Participant 11 mentioned "it opened us to the idea that some people shop more based on locally sourced items and items produced with the environment more in mind." This observation is also reinforced by the results of the first RQ, where we see that students' intentions toward sustainable action increased from before the workshop to the end of the semester. The results of the content analysis of students' reflections echo these results. Specifically, we see that 22 out of 23 students discussed the sustainable design heuristics and how they were incorporated into their design projects. The student reflections show that the workshop helped them focus on sustainability for their semester projects. For example, Participant 9 stated, "Especially when sustainability was one of our initial concerns, looking further into what actual makes something sustainable was extremely helpful and thought

provoking." This quote mirrors what many students said during the in-class discussion: that they did not know what sustainability encompassed before the workshop.

4. CONCLUSIONS, LIMITATIONS, AND DIRECTIONS FOR FUTURE WORK

Our aim in this study was to investigate the effects of participating in a sustainable design workshop on students' trait empathy and attitudes towards sustainability. We also aimed to explore students' perceived influence of participating in the workshop on their semester-long design projects. From the results, we see that students reported an increase in their attitudes and intentions towards sustainability from before the workshop to the end of the semester. On the other hand, we see no differences in students' trait empathy from before the workshop to the end of the semester. However, students also reported high levels of perspective-taking, fantasy, and empathic concern before the workshop. Finally, we see from our results that a majority of the students reported that participating in the workshop helped them refocus on empathizing with the user in their semester-long design project. These findings suggest the utility of participating in the workshop in increasing students' tendency to act sustainably and empathizing with the user.

Despite the important insights gained from our exploratory study, it has some limitations, which opens up several directions for future work. First, we used the three-component measure of attitudes towards sustainability proposed in [31] in our study; however, students' sustainable behaviors could be influenced by other individual differences such as personality, motivation, and self-efficacy [8], [10]. Therefore, future work must extend our findings towards the study of other individual differences beyond trait empathy and attitudes, behaviors, and intentions towards sustainability. This direction of research could also investigate the potential influence of gender in influencing sustainable design behavior [39]–[41]. Second, we introduced the sustainable design workshop in the last quarter of the semester-long project. Since at this point, students had already been through one iteration of the design process, they could have had a good understanding of the customers' needs, and therefore, a more positive perception of their empathic tendencies. This high perception could have, in turn, resulted in the high baseline trait empathy scores observed in the results of RQ1 (see Section 3.1). Therefore, future work should investigate how the timing of this workshop impacts students' trait empathy and the subsequent effects on their performance in the workshop. This direction of work should also investigate the introduction of sustainable design earlier in the design process (e.g., before the first iteration).

REFERENCES

[1] K. Jahan and Y. Mehta, "Sustainability Across the Curriculum," *Int. J. Eng. Educ.*, vol. 23, no. 2, 2007.

[2] J. S. Cooper, "Evolution of an interdisciplinary course in sustainability and design for environment," *Int. J. Eng. Educ.*, vol. 23, no. 2, pp. 294–300, 2007.

[3] C. I. Davidson, C. T. Hendrickson, and H. S. Matthews, "Sustainable engineering: A sequence of courses at Carnegie Mellon," *Int. J. Eng. Educ.*, vol. 23, no. 2, pp. 287–293, 2007.

[4] M. K. Watson, J. Pelkey, C. Noyes, and M. O. Rodgers, "Using Kolb's Learning Cycle to Improve Student Sustainability Knowledge," *Sustainability*, vol. 11, no. 17, p. 4602, Aug.

2019, doi: 10.3390/su11174602.

[5] A. S. Lau, “Green design in first-year engineering,” *Int. J. Eng. Educ.*, vol. 23, no. 2, pp. 276–286, 2007.

[6] J. M. Price and M. H. Minster, “Learning sustainability through the design process,” *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 2017-June, 2017, doi: 10.18260/1-2--28615.

[7] S. C. Ritter, E. Obonyo, A. S. Lau, and S. G. Bilen, “Client-Driven Project on Sustainability within First-Year Cornerstone Design,” in *2020 IEEE Global Humanitarian Technology Conference (GHTC)*, Oct. 2020, pp. 1–8, doi: 10.1109/GHTC46280.2020.9342888.

[8] A. R. B. Soutter, T. C. Bates, and R. Mõttus, “Big Five and HEXACO Personality Traits, Proenvironmental Attitudes, and Behaviors: A Meta-Analysis,” *Perspect. Psychol. Sci.*, vol. 15, no. 4, pp. 913–941, 2020, doi: 10.1177/1745691620903019.

[9] J. E. Desrochers, G. Albert, T. L. Milfont, B. Kelly, and S. Arnocky, “Does personality mediate the relationship between sex and environmentalism?,” *Pers. Individ. Dif.*, vol. 147, no. April, pp. 204–213, 2019, doi: 10.1016/j.paid.2019.04.026.

[10] M. McCormick, A. R. Bielefeldt, C. W. Swan, and K. G. Paterson, “Assessing students’ motivation to engage in sustainable engineering,” *Int. J. Sustain. High. Educ.*, vol. 16, no. 2, pp. 136–154, 2015, doi: 10.1108/IJSHE-06-2013-0054.

[11] D. N. Huntzinger, M. J. Hutchins, J. S. Gierke, and J. W. Sutherland, “Enabling sustainable thinking in undergraduate engineering education,” *Int. J. Eng. Educ.*, vol. 23, no. 2, pp. 218–230, 2007.

[12] J. J. Fitzpatrick, “Does engineering education need to engage more with the economic and social aspects of sustainability?,” *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 916–926, 2017, doi: 10.1080/03043797.2016.1233167.

[13] A. Wiek, L. Withycombe, and C. L. Redman, “Key competencies in sustainability: A reference framework for academic program development,” *Sustain. Sci.*, vol. 6, no. 2, pp. 203–218, 2011, doi: 10.1007/s11625-011-0132-6.

[14] G. de Haan, “The BLK ‘21’ programme in Germany: A ‘Gestaltungskompetenz’-based model for Education for Sustainable Development,” *Environ. Educ. Res.*, vol. 12, no. 1, pp. 19–32, 2006, doi: 10.1080/13504620500526362.

[15] R. van Dam-Mieras, A. Lansu, M. Rieckmann, and G. Michelsen, “Development of an Interdisciplinary, Intercultural Master’s Program on Sustainability: Learning from the Richness of Diversity,” *Innov. High. Educ.*, vol. 32, no. 5, pp. 251–264, Mar. 2008, doi: 10.1007/s10755-007-9055-7.

[16] S. Sterling and I. Thomas, “Education for sustainability: The role of capabilities in guiding university curricula,” *Int. J. Innov. Sustain. Dev.*, vol. 1, no. 4, pp. 349–370, 2006, doi:

10.1504/IJISD.2006.013735.

[17] K. Shephard, “Higher education for sustainability: Seeking affective learning outcomes,” *Int. J. Sustain. High. Educ.*, vol. 9, no. 1, pp. 87–98, 2008, doi: 10.1108/14676370810842201.

[18] E. Pappas and R. Kander, “Sustainable societies: The sustainable engineering design curriculum at James Madison University,” *ASEE Annu. Conf. Expo. Conf. Proc.*, 2008, doi: 10.18260/1-2--3445.

[19] M. H. Davis, “Measuring individual differences in empathy: Evidence for a multidimensional approach.,” *J. Pers. Soc. Psychol.*, vol. 44, no. 1, pp. 113–126, Jan. 1983, doi: 10.1037/0022-3514.44.1.113.

[20] N. D. Fila and J. L. Hess, “In their shoes: Student perspectives on the connection between empathy and engineering,” *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 2016-June, 2016, doi: 10.18260/p.25640.

[21] X. Tang, “From ‘empathic design’ to ‘empathic engineering’: Toward a genealogy of empathy in engineering education,” in *ASEE Annual Conference and Exposition, Conference Proceedings*, 2018, vol. 2018-June, doi: 10.18260/1-2--30538.

[22] D. G. Johnson, N. Genco, M. N. Saunders, P. Williams, C. C. Seepersad, and K. Hölttä-Otto, “An Experimental Investigation of the Effectiveness of Empathic Experience Design for Innovative Concept Generation,” *J. Mech. Des.*, vol. 136, no. 5, pp. 1–12, May 2014, doi: 10.1115/1.4026951.

[23] M. A. Alzayed, S. R. Miller, J. Menold, J. Huff, and C. McComb, “Can Design Teams Be Empathically Creative? A Simulation-Based Investigation on the Role of Team Empathy on Concept Generation and Selection,” in *Volume 8: 32nd International Conference on Design Theory and Methodology (DTM)*, Aug. 2020, pp. 1–15, doi: 10.1115/DETC2020-22432.

[24] M. Kouprie and F. S. Visser, “A framework for empathy in design: Stepping into and out of the user’s life,” *J. Eng. Des.*, vol. 20, no. 5, pp. 437–448, 2009, doi: 10.1080/09544820902875033.

[25] K. Brown *et al.*, “Empathy, place and identity interactions for sustainability,” *Glob. Environ. Chang.*, vol. 56, no. December 2018, pp. 11–17, May 2019, doi: 10.1016/j.gloenvcha.2019.03.003.

[26] E. Blevis, “Sustainable interaction design: Invention & disposal, renewal & reuse,” *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 503–512, 2007, doi: 10.1145/1240624.1240705.

[27] J. Hess and N. Fila, “The Development and Growth of Empathy Among Engineering Students,” in *2016 ASEE Annual Conference & Exposition Proceedings*, 2016, vol. 2016-June, doi: 10.18260/p.26120.

[28] A. O. Surma-Aho, T. A. Björklund, and K. Holtta-Otto, “Assessing the development of empathy and innovation attitudes in a project-based engineering design course,” *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 2018-June, 2018.

[29] J. L. Hess, N. D. Fila, and S. Purzer, “The relationship between empathic and innovative tendencies among engineering students,” in *International Journal of Engineering Education*, 2016, vol. 32, no. 3, pp. 1236–1249.

[30] M. Alsager Alzayed, C. McComb, J. Menold, J. Huff, and S. R. Miller, “Are you feeling me? An exploration of empathy development in engineering design education,” *J. Mech. Des.*, pp. 1–57, 2020, doi: 10.1115/1.4048624.

[31] K. H. D. Tang, “Correlation between sustainability education and engineering students’ attitudes towards sustainability,” *Int. J. Sustain. High. Educ.*, vol. 19, no. 3, pp. 459–472, Mar. 2018, doi: 10.1108/IJSHE-08-2017-0139.

[32] L. J. Cronbach, “Coefficient alpha and the internal structure of tests,” *Psychometrika*, vol. 16, no. 3, pp. 297–334, 1951, doi: 10.1007/BF02310555.

[33] S. Timmermans and I. Tavory, “Theory construction in qualitative research: From grounded theory to abductive analysis,” *Sociol. Theory*, vol. 30, no. 3, pp. 167–186, 2012, doi: 10.1177/0735275112457914.

[34] J. R. Landis and G. G. Koch, “The Measurement of Observer Agreement for Categorical Data,” *Biometrics*, vol. 33, no. 1, p. 159, 1977, doi: 10.2307/2529310.

[35] J. L. Hess, J. Strobel, and A. O. Brightman, “The Development of Empathic Perspective-Taking in an Engineering Ethics Course,” *J. Eng. Educ.*, vol. 106, no. 4, pp. 534–563, 2017, doi: 10.1002/jee.20175.

[36] C. D. Batson, S. Early, and G. Salvarani, “Perspective taking: Imagining how another feels versus imagining how you would feel,” *Personal. Soc. Psychol. Bull.*, vol. 23, no. 7, pp. 751–758, Jul. 1997, doi: 10.1177/0146167297237008.

[37] M. H. Davis *et al.*, “Cognitions associated with attempts to empathize: How do we imagine the perspective of another?,” *Personal. Soc. Psychol. Bull.*, vol. 30, no. 12, pp. 1625–1635, 2004, doi: 10.1177/0146167204271183.

[38] M. H. Davis, L. Conklin, A. Smith, and C. Luce, “Effect of perspective taking on the cognitive representation of persons: A merging of self and other.,” *J. Pers. Soc. Psychol.*, vol. 70, no. 4, pp. 713–726, Jul. 1996, doi: 10.1037/0022-3514.70.4.713.

[39] J. Harrison and L. Klotz, “Women as sustainability leaders in engineering: Evidence from industry and academia,” *Int. J. Eng. Educ.*, vol. 26, no. 3, pp. 727–734, 2010.

[40] D. R. Hokanson, L. D. Phillips, and J. R. Mihelcic, “Educating engineers in the sustainable futures model with a global perspective,” *Int. J. Eng. Educ.*, vol. 25, no. 4, pp. 255–263, Dec. 2007, doi: 10.1080/10286600802002981.

[41] J. B. Zimmerman and J. Vanegas, “Using sustainability education to enable the increase of diversity in science, engineering and technology-related disciplines,” *Int. J. Eng. Educ.*, vol. 23, no. 2, pp. 242–253, 2007.

APPENDIX:

Topic	Themes	Description
Experiences with the workshop	Positive	The participant discusses their positive experiences with the sustainability design challenge
	Negative	The participant discusses their negative experiences with the sustainability design challenge
	Indifferent	The participant discusses their indifference with the sustainability design challenge. Do not select this node if the participant did not address the question.
Utility of Workshop with Design Process	Empathize	The participant discusses understanding the users needs through connecting with the user
	Define	The participant discusses the act of defining the customer needs or problem statement.
	Ideate	The participant discusses coming up with ideas or concept selection
	Prototype	The participant discusses the act of prototyping or the way they would prototype.
	Test	The participant discusses the test procedures or results of testing
Utility of Workshop to Help Empathize with User	Positive	The participant discusses the positive impact of the sustainability challenge on their ability to empathize with the end-user
	Negative	The participant discusses the negative impact of the sustainability challenge on their ability to empathize with the end-user
	No impact	The participant discusses that sustainability challenge had no impact on their ability to empathize with the end-user. Do not select this node if the participant did not address the question.
Empathic Tendencies [19]	Perspective Taking	The participant discusses this empathic tendency: “the ability to adopt the perspectives of other people and see things from their point of view”
	Fantasy	The participant discusses this empathic tendency: “the tendency to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays”
	Empathic Concern	The participant discusses this empathic tendency: “the degree to which the respondent experiences feelings of warmth, compassion and concern for the observed individual”

Topic	Themes	Description
	Personal Distress	The participant discusses this empathic tendency: “individual's own feelings of fear, apprehension, and discomfort at witnessing the negative experiences of others”
Sustainability	Beliefs	The participant discusses perceptions of issues related to sustainability e.g. moral obligation or responsibility
	Attitudes	The participant discusses awareness and actions toward sustainable goals
	Intentions	The participant discusses their intent to take action toward sustainable goals
Sustainable Design Heuristics	Disposal	The participant discusses this sustainability heuristic
	Salvage	
	Recycle	
	Remanufacture for Reuse	
	Reuse as is	
	Longevity	
	Sharing for maximal use	
	Achieving heirloom status	
	Finding wholesome alternatives	
	Active repair of misuse	