International Journal of Engineering Education Vol. 38, No. 3, pp. 695–708, 2022
Printed in Great Britain

0949-149X/91 $3.00+0.00
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Exploring the Relationship between Students' Trait Empathy, their Attitudes Towards Sustainability, and their Reflections on a Workshop on Sustainable Design*

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Now more than ever before, there is a need for engineering solutions to global environmental problems. Towards this need, we see an increase in efforts towards incorporating sustainability into engineering education and particularly in engineering design education. Despite this work, there remains the need to investigate the influence of these interventions on students' individual differences, especially their trait empathy and attitudes towards sustainability. Such an investigation is important as these individual differences could influence students' ability to relate to sustainability-focused issues and act upon them. Consequently, our goal in this paper is to investigate this research gap by exploring the relationship between students' individual differences – specifically, their trait empathy and attitudes towards sustainability – and their reflections on a sustainable design workshop in relation to a semester-long design project. Towards this goal, we conducted an exploratory study with 40 first-year engineering students from a large public university in the northeastern United States. The main findings from this study indicate the positive impact of participating in the sustainable design workshop on students' attitudes and intentions towards sustainability in addition to their perceived positive experiences with the workshop. These findings could inform future efforts towards devising pedagogical interventions that encourage a sustainability-focused mindset among engineering students, through engineering design education.

Keywords: engineering design education; sustainability; empathy; student experiences

1. Introduction

As natural resources deplete, there is an increased emphasis on the need for a sustainable mindset among individuals. Moreover, given the important role of engineers in addressing the world's crises [1], engineering education must place a special emphasis on sustainability. Several researchers have discussed methods to incorporate the technical aspects of sustainability (e.g., manufacturing, circular economy, and lifecycle analysis) in engineering education [2]; however, educators must also emphasize the social and economic aspects of sustainability in engineering education [3]. Similarly, several researchers (e.g., see [4, 5]) have argued for the need for developing interpersonal competencies such as empathy and compassion among future engineers to cultivate a sustainable mindset in them.

Empathy is also seen as a core tenet of engineering education as it helps engineering students foster a deep understanding of both, the design problem and the users [6]. Moreover, the cultivation of empathy in the classroom aligns with the recent push to reform engineering education, from only focusing on technical skill development towards a holistic approach incorporating the development of social competencies [4, 7, 8]. Empathy is a particularly important component in this holistic educational approach given the importance of empathy when engaging with stakeholders and understanding different cultural expectations [7]. Empathy becomes even more important when designing for users who are unlike the designer, which is often the case in engineering design and product development [9, 10].

Several researchers have investigated empathy development and its subsequent effects on the outcomes of engineering design education (e.g., see [6, 11]). Additionally, researchers have proposed educational interventions for teaching sustainable design (e.g., [12]) with some interventions emphasizing the social aspects of sustainability (e.g., [13]).

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* Accepted 20 November 2021.

Despite the growing body of research integrating sustainability in engineering education, little research has explored the relationship between students' trait empathy and the outcomes of sustainable design education. This lack of exploration is problematic because designers' ability to relate to others' problems, i.e., their perspective-taking – a component of empathy – could determine the extent to which they relate to the issues of sustainability. Furthermore, to fully appreciate and relate to the issues caused by unsustainable actions, designers must place themselves in the shoes of those who are directly affected by these actions. By empathizing with those who suffer from the outcomes of unsustainable actions, designers could be placed in a better position to actively adopt sustainable design methods and develop meaningful and impactful solutions.

Consequently, our aim in this paper is to explore this research gap by investigating the relationship between students' individual differences – specifically, their trait empathy and attitudes towards sustainability – and their reflections on a sustainable design workshop concerning a semester-long design project. The findings from this study could inform future work into formulating pedagogical interventions that encourage a sustainability-focused mindset among engineering students, through engineering design education.

In the next section, we present a review of prior work that informed this research. Next, in Section 3, we present the research questions we seek to explore in this research, and our predicted hypotheses. This section is followed by a discussion of the experimental methods used to answer the research questions, presented in Section 4. The data collected from the experiment are analyzed using qualitative and quantitative methods, and the details of the analyses, as well as the corresponding results, are presented in Section 5. Next, the implications of these results for design education are discussed in Sec. 6, followed by limitations, directions for future work, and conclusions presented in Sections 7 and 8.

2. Related Work

To lay the foundation for the current investigation, we explored previous research on (1) sustainability in engineering education, and (2) the role of empathy in engineering education. The key findings from this review of prior work are discussed in this section and serve as the basis for our research.

2.1 Sustainability in Engineering Design Education

As environmental sustainability becomes a topic of interest in engineering, there has been an increased interest in integrating sustainability in engineering education. This integration has been achieved through the introduction of topics such as life cycle analysis and circular economy in engineering education [14], and especially, engineering design education [15–17]. Furthermore, these initiatives have been introduced at various stages of the engineering curriculum, with some initiatives introduced as early as the first year of education [18–20]. Some examples of initiatives proposed in the first year include the three-part sequence of courses on sustainable design suggested by Price and Minster [19] and the half-semester project proposed by Ritter et al. [20]. In the former, the authors compare survey responses collected at the beginning and end of the course to demonstrate that participating in the course increased students' sustainable design knowledge and their confidence in integrating these concepts in design. In the latter, the authors take a systems-design approach and encourage students to consider the social, environmental, and economic impact of their solutions, both direct and indirect. Some other efforts include the eco-design-focused course investigated by Kattwinkel et al. [21], the graduate-level program discussed by Valderrama Pineda and Niero [12], and the use of service design-based initiatives proposed by Kuzmina et al. [22, 23].

Although the emphasis on environmental sustainability is important, engineering educators must make special efforts to emphasize the social aspects of sustainability, as these concepts are often difficult to implement [3, 24–28]. For example, Björnberg et al. [29] present a study comprising interviews with engineering educators. From analyses of these interviews, they observe that educators find it particularly difficult to teach the social aspects of sustainability. Moreover, based on their study, the authors suggest that this difficulty could be attributed to the lack of effective educational methods for teaching the social aspects of sustainability. Another similar study is presented by Mesquita and Missimer [13]; in their sustainable design workshop, students are introduced to both, the social and environmental aspects of sustainable design through the provision of external cues. From an evaluation of the workshop, the authors observe that despite the use of external cues, students found it difficult to integrate sustainability in their design process, and this was true for both, the social and environmental aspects. Another similar effort is presented by Pappas and Kander [30]; in this six-semester program introduced at James Madison University, students are introduced to sustainability from an economic, cultural, and social lens.

While the interventions proposed in these studies help educators effectively introduce sustainable design in engineering design education, students' tendency to actively utilize these concepts in their

design process could be governed by several individual differences [31–33]. This influence of individual differences could be particularly concerning as the students from developed countries might not have direct experiences with issues related to sustainability. Therefore, they might have to make more effort to successfully empathize with those suffering from these issues [5, 34]. Similarly, arguments have also been made suggesting the need to develop interpersonal competencies such as empathy, compassion, and internal motivation, to ensure the effectiveness of sustainability-focused education (e.g., see [24–26]); however, these relationships remain largely unexplored [35], especially in engineering design education.

In summary, we see that several educational methods have been proposed to incorporate sustainability into engineering education, and especially in engineering design education. Despite this work, little research has explored the influence of these interventions on students' individual differences such as their trait empathy and attitudes towards sustainability. This lack of exploration could be problematic as students' ability to relate to issues related to sustainability could be governed by their trait empathy. On the other hand, their tendency to act upon these issues could be governed by their attitudes towards sustainability. Our aim in this paper is to investigate this research gap by exploring the relationship between students' individual differences – specifically, their trait empathy and attitudes towards sustainability – and their reflections on a sustainable design workshop in relation to a semester-long design project. Before doing so, prior work on empathy in engineering design education is reviewed as discussed next.

2.2 Empathy in Engineering Design Education

Empathy, or the "reactions of the individual to the observed experiences of another" [36], has been identified as an essential component of engineering due to the role of empathy in supporting engineers in engaging with numerous and diverse stakeholders and understanding different cultural expectations. Empathy has been particularly important in engineering design education as it has been shown to help student designers to deeply understand the design problem [37], and the needs of the end-users involved [9, 10, 38]. For example, in a qualitative study by Hess and Fila, empathy has been attributed to allowing for effective teamwork, problem contextualization, and individual design inspiration among engineering students. Cultivating empathic experiences in the classroom (e.g., introducing students to a wheelchair) has also been to increase students' perceptions of the relevance of their coursework in impacting the world. Moreover, Surma-Aho et al. [39] found that trait empathy was positively related to students' confidence in design-related experiments.

In the concept generation stage of the design process, the engagement in empathic design experiences (e.g., simulating visually impaired scenarios) has been found to impact engineering students' ability to generate creative ideas [6, 40, 41] that are rated high in quality, novelty, and variety. On the same line of research, Alsager Alzayed et al. [11] found that three of four empathic tendencies (empathic concern, personal distress, perspective-taking) were all related to creative ideation. Specifically, students' empathic concern tendencies positively impacted the number of ideas generated by students, whereas perspective-taking and personal distress tendencies negatively impacted the number of ideas generated. In the concept selection stage of the design process, the same group of researchers found that student designers' perspective-taking tendencies positively related to their selection of elegant ideas [42].

While this prior work explored the impact of empathy on student design outcomes in engineering education, a majority of prior work has focused on students' ability to relate to the needs of the primary end-users involved in a design problem. Little is known about the impact of empathy on actions directed to benefit others *indirectly*, particularly in the context of sustainability. This lack of research could be problematic as students' empathy could influence their ability to identify with issues related to sustainability, and also act towards addressing these issues. Motivated by this gap in research, our aim in this paper is to investigate the relationship between students' trait empathy, their attitudes towards sustainability, and their reflections on a workshop on sustainable design.

3. Research Questions

Our aim in this paper is to investigate the relationship between students' trait empathy, their attitudes towards sustainability, and their reflections on a sustainable design workshop. Towards this aim, we seek to explore answers to the following research questions (RQs):

- ***RQ1: How do students' attitudes towards sustainability and trait empathy compare from before the workshop to the end of the semester?*** We hypothesize that students will report an increase in their attitudes towards sustainability from before the workshop to the end of the semester. Introducing students to the various sustainable design heuristics as well as issues related to sustainability would result in more positive attitudes towards

acting sustainably. Additionally, we hypothesize that completing the design activity would trigger students' empathic tendencies, resulting in them reporting an increase in trait empathy.

- ***RQ2: What were students' experiences in the sustainable design workshop and how did it impact their perceived use of empathy and sustainability concepts in their semester-long project?*** We hypothesize that students would report a positive experience with the workshop and would find the workshop to be useful in their final semester-long project. Specifically, we hypothesize that students will report employing sustainable design heuristics in their semester-long design projects. Furthermore, we hypothesize that students would find the workshop to be most useful in informing the 'empathize' stage of the design process. These hypotheses are based on previous research (e.g., [14, 20]) demonstrating the utility of project-based educational workshops and modules in encouraging the use of sustainability in engineering design.

4. Experimental Methods

To answer the research questions presented in Section 3, we conducted an experiment. The experiment was conducted in the form of a workshop with 40 first-year engineering students from a large public university in the northeastern United States. The details of the experimental methods and metrics are discussed in the sections that follow.

4.1 Participants

Participants in this study include 40 engineering students recruited from a first-year introductory course on Engineering design at a large public university in the northeastern United States. The participants primarily comprised of first-year students (n = 36), with two students in their second year of study, one student in their third year of study, and one student in their fourth year of study. The participants were recruited from two sections of the first-year course with both sections having the same instructor and following the same course structure. Moreover, both sections were at the same point in the course and therefore, had similar levels of prior experience. The two sections were randomly assigned to one of the two experimental conditions, as discussed in Section 4.2.2. Students from this first-year design course were selected for this study since empathy and sustainability are part of the learning outcomes of this course [20, 43]. Moreover, the course encourages students "to identify affected stakeholders and their needs, and incorporate those needs into the project description and design goals" (p.3, [44]). However, we acknowledge that the choice of participants being primarily in their first year of study is a potential limitation of this research and future work will expand our findings towards students with different levels of experience.

4.2 Procedure

Before beginning the experiment, students were given an overview of the study and its purpose, and consent was obtained through email, per IRB protocol, since the experiment was conducted online. The experiment was conducted over two days with each day comprising a 1.5-hour session and with one day between the two sessions. The experiment was conducted in two sections of a course on introductory engineering design and the overall experimental procedure is summarized in Fig. 1. As seen in the figure, the experiment comprised a design activity and a lecture on sustainability. Additionally, as shown in Fig. 1, one of the sections (Section A, N = 22) received the sustainability lecture at the beginning of the experiment, whereas the second section (Section B, N = 18) received the lecture at the end of the experiment. This variation was introduced to test if the order of the lecture and design activity influenced the outcomes of the workshop.

4.2.1 Pre-Intervention Survey

At the beginning of the workshop, students were asked to complete a pre-intervention survey comprising the 28-item Interpersonal Reactivity Index (IRI) [36] to collect their trait empathy, and a 25-

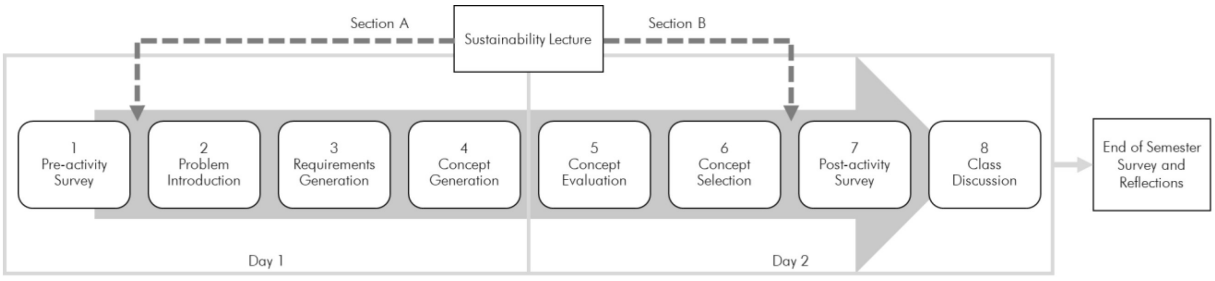

Fig. 1. Overview of the experimental procedure.

item survey collecting their attitudes toward sustainability [45]. The *IRI* measures individuals' trait empathy on four components: (1) perspective taking, (2) fantasy, (3) empathic concern, and (4) personal distress [36], with seven items under each component. Meanwhile, the *attitudes toward sustainability* [45] survey measures students' attitudes towards sustainability on three components: (1) beliefs (six items), (2) attitudes (thirteen items), and (3) intentions (six items). Both instruments (the IRI and attitudes towards sustainability survey) involve responding to items on a 5-point Likert-type scale ranging from 1 = "Strongly Disagree" to 5 = "Strongly Agree". More details about these tools can be found in Section 4.3 in which all metrics used in this paper are discussed in detail. In addition to these two scales, demographic information such as year of study and gender was also collected. Since the experiment was conducted virtually, the pre-intervention survey was administered using Microsoft Forms.

4.2.2 Sustainable Design Lecture

The next component of the experiment was a lecture on sustainable design. In this lecture, students were first introduced to the definition of sustainability as "Meeting the needs of today without diminishing the ability of future generations to meet their needs," and were introduced to the three pillars of sustainability: environment, society, and economy. Then, they were briefly introduced to life cycle assessment and the ten sustainable design heuristics proposed by Blevis [46]: (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. When discussing life cycle assessment, students were introduced to the idea of cradle to grave assessment and how the environmental cost of a product is determined during the design of the product. Additionally, the ten sustainable design heuristics were included given their similarity to other design tools proposed in the literature (e.g., see [47]). Finally, students were also briefly introduced to the 17 United Nations (UN) sustainable development goals (SDGs) with a particular focus on goal #6: Clean Water and Sanitation, which was used to contextualize the design problem in the design activity. While participants from Section A (N = 22) were given the lecture before the design activity, students from Section B (N = 18) received the same lecture after the design activity.

4.2.3 Design Activity

As part of the design activity, students were introduced to the design task and the design prompt for this activity. This design prompt focused on access to clean water (SDG #6):

> *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.*

Students were given also some background on the problem and a persona to help identify customer needs and to generate concepts in the form of 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.*

After receiving the prompt, students were given 20 minutes to develop five problem requirements. Next, participants were given 15 minutes to generate as many ideas as possible for the design problem. After concept generation, students evaluated their concepts and selected their best design to move forward with using a concept selection matrix. After selecting their design, students rated their design on how well it met the problem requirements identified by them and on the sustainable design heuristics presented during the sustainability lecture. Students completed all parts of the design activity individually. At the end of the second day of the experiment, students were engaged in an open class discussion on their experiences with the workshop.

4.2.4 End of Semester Reflection

After the two sessions of the workshop, the students continued to work on their semester-long design project for three weeks. At the end of the semester, after completing the semester-long design project, students were asked to submit a reflection on the sustainability workshop and complete an end-of-semester survey. For the reflection assignment, students were asked to summarize their experiences with the sustainability workshop and reflect on how

participating in the workshop influenced their decisions in their semester-long design projects. Specifically, students were 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?

Students' responses to the reflection assignment were analyzed using content analysis to answer RQ2. Furthermore, participants' responses to the pre-workshop and end-of-semester surveys were compared to answer RQ1.

4.3 Metrics and Coding Schemes

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

4.3.1 Pre-intervention and End of Semester Survey

Students were asked to complete a survey collecting their trait empathy and their attitudes towards sustainability before the workshop and at the end of the semester. The specific measures used to capture these two constructs are discussed next.

- ***Trait Empathy:*** The students' trait empathy was measured using the Interpersonal Reactivity Index (IRI) [36]. The IRI measures individuals' trait empathy on four components: (1) perspective taking, (2) fantasy, (3) empathic concern, and (4) personal distress. Perspective-taking measures the ability "to adopt the perspectives of other people and see things from their point of view (p. 2, [48]); fantasy measures "the tendency to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays" (p. 12, [48]); empathic concern, measures "the degree to which the respondent experiences feelings of warmth, compassion and concern for the observed individual" (p. 12, [48]); and personal distress measures an "individual's own feelings of fear, apprehension, and discomfort at witnessing the negative experiences of others" (p. 12, [48]). 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 [49,50]. Additionally, the IRI has been used in prior studies in engineering design research to measure designers', and especially student designers' trait empathy (e.g., see [38, 39, 51]).
- ***Attitudes towards Sustainability:*** The 25-item survey used developed by Tang [45] 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 [52] > 0.7 for each component of both parts of the survey.

4.3.2 Coding Scheme Used to Analyze Student Reflections

Students' responses to the reflection essays (see Section 4.2.4) were coded through an abductive content analysis approach [53]. 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 [54] (Cohen's Kappa = 0.67), one of the raters coded the remaining data.

5. Data Analysis and Results

The data collected in the experiment is analyzed to answer the three research questions presented in Section 3. The results of the analyses are discussed in the remainder of this section.

5.1 RQ1: How do Students' Attitudes towards Sustainability and Trait Empathy Compare from before Participating in the Workshop to the End of the Semester?

The first research question was devised to assess the change in students' trait empathy and attitudes towards sustainability from before participating in the workshop to the end of the semester. The students' responses to the IRI and Attitudes towards Sustainability scales collected pre-inter-

Table 1. Main effects of time (pre-intervention to end of the semester) and the interaction effects with the section (lecture-first vs design activity first) on attitudes towards sustainability

	F	*p*	*Partial Eta Squared*
Beliefs			
Time	0.535	0.469	0.014
Time * Section	3.018	0.090	0.074
Attitudes			
Time	5.897	0.020*	0.134
Time * Section	0.144	0.706	0.004
Intentions			
Time	14.143	<0.001 *	0.271
Time * Section	0.617	0.437	0.016

* Indicates $p < 0.05$.

vention and at the end of the semester were compared. First, the internal consistency of the students' responses was validated through an observed Cronbach's $\alpha > 0.7$ [52] for each component of the two surveys. Next, items within each component were added to obtain a total score for each component. The total component scores were compared using repeated-measures ANOVA, with the time (i.e., pre-intervention and end of the semester) as the within-subjects factor. Additionally, the section (i.e., lecture first vs design activity first) was added as a between-subjects factor to test if there were any differences between the two sections.

From the results, we observe a significant *positive change* in students' attitudes and intentions towards sustainability ($p < 0.05$) with no significant effects observed on their beliefs towards sustainability, see Table 1. Specifically, students' attitudes and intentions towards sustainability increased from pre-intervention to the end of the semester, see Fig. 2. This finding is encouraging since students' tendency to engage in sustainable behavior could, in turn, increase the active adoption of sustainable design practices. Moreover, we see no significant impact of the section (Section A and Section B) suggesting that the order of the lecture and design activity did not have an impact on changes in students' sustainability attitudes, beliefs, and intentions.

Table 2. Investigating the effects of time (pre-intervention and end of the semester) and the interaction effects with the section (lecture first vs design activity first) on the components of trait empathy

	F	*p*	*Partial Eta Squared*
Perspective Taking			
Time	0.091	0.765	0.002
Time * Section	0.016	0.900	0.000
Fantasy			
Time	2.104	0.155	0.052
Time * Section	0.062	0.805	0.002
Empathic Concern			
Time	0.076	0.784	0.002
Time * Section	1.308	0.260	0.033
Personal Distress			
Time	5.776	0.021*	0.135
Time * Section	2.160	0.150	0.055

* Indicates $p < 0.05$.

While students' attitudes and sustainability attitudes increased, we see no significant change in students' perspective-taking, fantasy, and empathic concern tendencies, see Table 2. Furthermore, we see no significant interaction effects of time of survey and course section on students' trait empathy. However, we see a significant *negative change* in participants' tendency to feel personal distress, see Table 2. Specifically, students' personal distress tendencies decreased from pre-intervention to the end of the semester, see Fig. 3.

5.2 RQ2: What were Students' Experiences in the Sustainable Design Workshop and how did it Impact their Perceived Use of Empathy and Sustainability Concepts in their Semester-long Project?

The second research question was devised to assess students' experiences in the sustainable design workshop and how it influenced their perceived

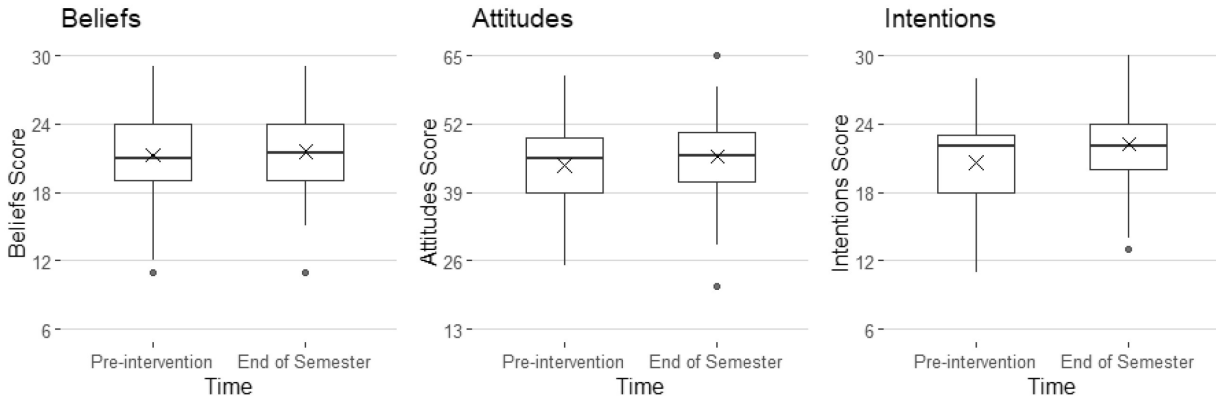

Fig. 2. Comparing attitudes towards sustainability from before the intervention to the end of the semester.

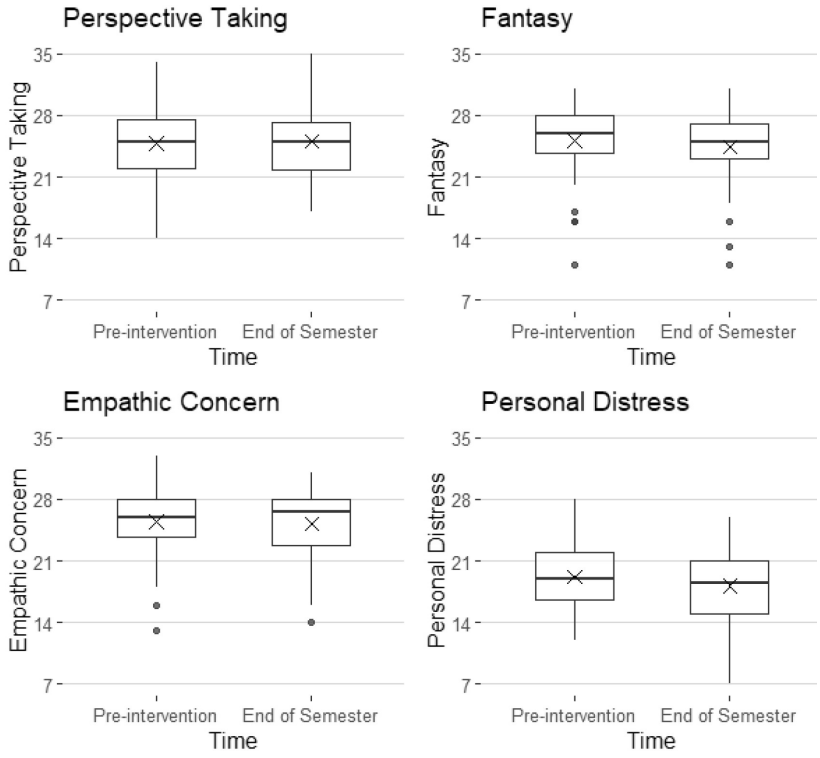

Fig. 3. Comparing components of trait empathy from before the intervention to the end of the semester.

use of empathy and sustainability concepts in their semester-long design project. To address this research question, student reflection essays collected at the end of the semester were coded using an abductive content analysis approach (see appendix for the detailed codebook).

The results from the content analysis revealed that a majority of students (n = 35) reported positive experiences with the workshop on sustainable design. Additionally, four students reported negative experiences and three students discussed the impact of the workshop but did not express their feelings on the impact (indifferent). Importantly, the four students who reported their negative experiences of the workshop also discussed positive aspects of their experience. For instance, participant #28 mentioned "My experience with the design challenge was mostly positive, however, it did have some negative parts. One main problem that I had with it was I didn't understand the problem that we were trying to solve enough." Similarly, participant #32 mentioned, "I did not really like the sustainability design challenge . . . however, it did help me learn more about sustainability and how to design a product that is sustainable." This analysis revealed that the vast majority of students reported positive outcomes from the design challenge.

Additionally, the data from the content analysis indicated that students discussed the utility of the sustainable design workshop in relation to the five design stages. Specifically, students were mostly citing the influence of the workshop on the following design stages: (a) empathizing with the user (n = 36), (b) problem definition (n = 25), and (c) ideation (n = 28); see Fig. 4 for the breakdown of the responses per course section. These findings highlight the role of the workshop in encouraging the early conceptual stages of the design process.

In addition to the discussion of design stages, we observed that a majority of students felt that the workshop had a positive impact on their ability to empathize with the end-user (n = 24), and eight students believed the workshop had no impact on their ability to empathize with the end-user. However, no students discussed that the workshop had a negative impact on their ability to empathize with the end-user. In order to deepen our understanding of the impact of the workshop on participants' empathy, we observed students' discussion of each of the four empathic tendencies (empathic concern, perspective-taking, fantasy, and personal distress, see section 4.2.1). The results from the content analysis revealed that students were mainly discussing their perspective-taking (n = 10) and, empathic concern (n = 13) tendencies. Only one participant discussed their personal distress tendencies, and no participants cited their fantasy tendencies. For example, participant #7 discussed their perspective-taking tendencies, "This challenge helped me

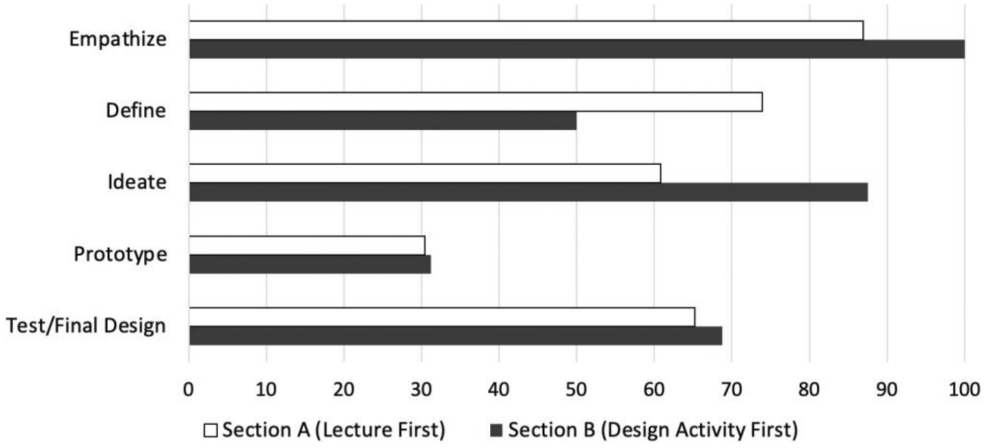

Fig. 4. Percentage of participants in each course section that discussed each of the five design stages.

get comfortable with having empathy and placing myself in another's situation''.

Additionally, in terms of students' attitudes towards sustainability, we observed that students discussed their beliefs, attitudes, and intentions on sustainability. Specifically, the majority of students (n = 34) cited their intentions towards sustainability. Moreover, 27 students discussed their attitudes towards sustainability and 19 students discussed their beliefs on sustainability. For example, participant #8 cited their beliefs towards sustainability, ''Improving access to clean water and sanitation is a very serious concern to solve and it was difficult to come up with ideas that were also sustainable and environmentally friendly.''

During the workshop, students were given a lecture on ten sustainable design heuristics (see Section 4). Notably, Section A received the lecture before the design activity while Section B received the lecture after the design activity. Almost all students, from both sections, discussed at least one design heuristic. Of those ten heuristics, students discussed their use of all of the heuristics in the design challenge. Students from both sections focused on the following heuristics: (1) longevity (n = 24), (2) recycle (n = 18), and (3) finding wholesome alternatives (n = 17).

However, it was noticed that students that received the lecture pre-activity focused on different design heuristics (see Fig. 5). For example, heuristics such as achieving heirloom status, sharing for maximal use, and active repair of misuse were discussed by more than 20% of students from Section A (lecture first) compared to Section B

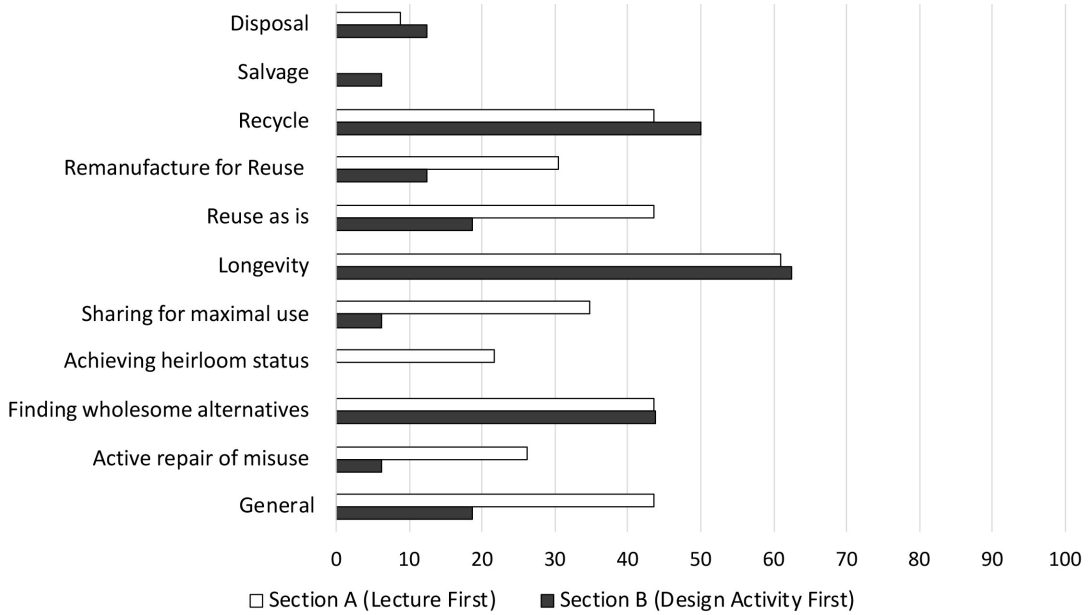

Fig. 5. Percentage of participants in each course section that discussed the various sustainability heuristics.

(design activity first). This finding shows the utility of the lecture on sustainability in encouraging students to utilize a variety of sustainability heuristics. These findings further encourage the development of pedagogical interventions such as lectures to reinforce the integration of sustainability concepts in engineering design education curricula.

6. Implications on Engineering Design Education

Our goal in this research is to investigate the relationship between students' trait empathy, their attitudes towards sustainability, and their reflections on a workshop on sustainable design. The main findings from this study indicate the positive impact of participating in the sustainable design workshop on students' attitudes and intentions towards sustainability in addition to their perceived positive experiences with the workshop. In the remainder of this section, we discuss the implications of these results including the main findings below:

- Students' attitudes and intentions towards sustainability increased from before the workshop to the end of the semester; however, their beliefs did not change.
- Students reported that participating in the workshop positively influenced their skills in the empathize stage of the design process.
- Students reported the use of all ten sustainability heuristics in their semester-long project.

The first key finding from the results is that students' attitudes and intentions towards sustainability increased from before the workshop to the end of the semester. This is a positive finding as it suggests that after participating in the workshop, students demonstrate an increase in their intentions to engage in sustainable behavior. These findings corroborate with the qualitative findings that found that most students cited their intentions (n = 34) and attitudes (n = 27) towards sustainability. This finding is encouraging since students' tendency to engage in sustainable behavior could, in turn, increase the active adoption of sustainable design practices. It is important to note that this increase happened over 3 weeks after students both completed the sustainability workshop and applied the concepts to their semester-long design project. Future research should, therefore, investigate whether the workshop, the application of the concepts, or a combination of the two contributed to the change in sustainability intentions and attitudes. Moreover, such an investigation must investigate the retention of these attitudes over longer periods of time.

The second, finding is that a majority of students (n = 36) reported that participating in the workshop helped them to empathize with the user. Specifically, students reflected on their perspective-taking (n = 13) and empathic concern (n = 10) tendencies when relating the workshop to their semester-long project. This finding is encouraging as it shows that students were discussing both the cognitive (e.g., perspective-taking) and affective (e.g., empathic concern) components of their empathy. Prior work by Hess and Fila [49] has described that both cognitive and affective components are essential to help designers understand end-user needs.

Although our qualitative findings found the utility of the workshop on students' ability to empathize with the end-user, the survey results indicated that there was not a significant change in students' trait empathy. Specifically, we see a lack of change in students' fantasy, empathic concern, and perspective-taking, and a decrease in their personal distress tendencies. This decrease in personal distress tendencies could be indicative of the emotion regulation skills of students in the sample we studied since prior research has attributed personal distress tendencies to emotional vulnerability [55] and empathic over-arousal [56].

Third, the analysis of the reflection essays revealed that almost all students (n = 38) discussed at least one of the ten sustainable design heuristics. Of the ten heuristics, students discussed their use of all of the heuristics in the design workshop and focused on the following heuristics: (1) longevity (n = 24), (2) recycle (n = 18), and (3) finding wholesome alternatives (n = 17). However, we found that students that received the lecture first discussed the following heuristics more compared to students that received the lecture after the design activity: (1) achieving heirloom status (n = 6), (2) sharing for maximal use (n = 9), and (3) active repair of misuse (n = 7). This finding shows the utility of the lecture on sustainability in encouraging students to utilize more sustainability heuristics. This result could also be linked to the fact that those who received the lecture first had an additional opportunity to practice the use of sustainability heuristics through the workshop [57], whereas, the other section was given only one opportunity to practice through the semester design project. These results further encourage the development of pedagogical interventions such as lectures to reinforce the integration of sustainability concepts in engineering design education curricula.

Taken together, the results from this study present the utility of the sustainable design workshop in improving students' intentions and attitudes towards sustainability in addition to allowing students to empathize with the end-user. Moreover,

since the design activity used in the workshop focused on the first half of the design process (empathize, define, and ideate), students' focus on these stages in their reflections highlights their ability to make connections between the material covered in the workshop and their semester-long project. The additional focus on the test phase and final design is also worth noting as it indicates that students are applying the lessons learned in this workshop to their final project design. Furthermore, since the workshop was conducted at the end of the semester as students were entering the testing phase of their semester-long design project, it is evident that students were applying their knowledge gained from this activity to the final design. This connection of the sustainability workshop to the test and final design phases of the semester-long project also aligns with the increase in sustainability attitudes and intentions as observed in the survey responses.

7. Limitations and Directions for Future Work

While this study provided interesting insights in the direction of sustainable design education, there are several limitations that present opportunities for future research. First, while this study measured students' trait empathy and attitudes towards sustainability, future research is warranted to study other individual differences (e.g., personality traits [31]) that could impact students' sustainable design practices. Second, the workshop was given to students in the second half of the semester where students were finishing up their semester-long project. Given the timing of the workshop, students could have already gained some experience in empathizing with users through their user-centered project. Future research should, therefore, investigate whether the timing of the workshop (i.e., beginning vs. end of the semester) impact students' experiences in the workshop, as well as how the integration into the classroom impacts learning and application of sustainability in design (e.g., see work in [58]). Third, the workshop did not explicitly ask students to consider sustainable design in relation to empathy, nor were they explicitly asked to use their empathy in the design activity. Thus, future research should devise and assess the involvement of empathy-evoking interventions (e.g., see work in [59, 60]) in the context of sustainable design. Finally, prior research suggests that the design processes and learning patterns of first-year and senior students differ on numerous dimensions such as solution quality and time spent on the problem [61, 62]. The participants in our study comprised only first-year students, and, therefore, future research is warranted to extend the findings from this study with different levels of experience.

8. Conclusions

Our goal in this paper was to investigate the relationship between students' trait empathy, their attitudes towards sustainability, and their reflections on a workshop on sustainable design. Towards this research goal, we conducted a study with 40 first-year engineering students. From our results, we see a positive change in students' attitudes and intentions towards sustainability from before the workshop to the end of the semester. Additionally, students reported that the workshop had a positive impact on their ability to empathize and take sustainability into account in their semester-long project. From these findings, we conclude that a brief workshop on sustainable design has the potential to positively influence students' integration of sustainable design in a longer design project. The findings from this study also lay the foundation for devising pedagogical interventions that encourage a sustainability-focused mindset among engineering students, through engineering design education.

Acknowledgements – An earlier version of this work has been published as part of the Proceedings of the 2021 American Society of Engineering Education Annual Conference & Exposition [63]. © 2021 American Society for Engineering Education.

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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 to 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 the 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 [36]	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''.
	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	

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