Emotions in Education for Sustainability in Engineering

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Abstract

This study examined the role of emotions in sustainability education. Faculty reflections on their own emotions and their perceptions of student emotions related to sustainability education in engineering were analyzed. The findings were then connected to emotionally conscious, effective teaching strategies in sustainability education within engineering. The research was part of a larger study grounded in the Diffusion of Innovation theory. Ten interviews were conducted with innovators and early adopters of educating mechanical engineering students about sustainability in the U.S. and Canada. Following the discrete emotions framework of the HUMAINE database, 48 emotions were used as an initial coding framework. The total number of different emotions attributed to faculty and/or students within each interview ranged from 5 to 24, with some faculty speaking in much more emotional language than others. In six of the interviews there were more distinct positive emotions than negative emotions evident for both students and faculty. The most common faculty emotion was interest in sustainability and enjoyment (pleasure) teaching sustainability; similar emotions were attributed to students learning about sustainability issues. However, two interviewees used the term “doom and gloom” in reference to their own feelings and their perceptions of the feelings of their students with respect to the (un)sustainability of the planet; it is unclear whether these feelings are best characterized as despair, anxiety, and/or fear. The interviewees connected emotions to their sustainability teaching practices in a variety of ways. This included role modeling for students being mindful of their emotions when discussing sustainability, showing that there are positive steps that can be taken, making learning interesting and fun through games, and empowering students to be a piece of the puzzle in creating change. The results speak to the importance of considering emotions when designing teaching approaches related to sustainability.

Introduction

There is generally strong consensus that it is important to educate engineers to contribute to sustainable development, inclusive of social, environmental, and economic aspects for current and future generations [1]. Outside of engineering, the Education for Sustainability movement has long emphasized the importance of both cognitive and affective outcomes, but its application in engineering has been limited. In a study grounded in the Diffusion of Innovation theory, ten innovators and early adopters of educating mechanical engineering students in the U.S. and Canada about sustainability were interviewed about their experiences and practices. Although the individuals were not directly asked to discuss emotions, this emerged as an important theme in many of the responses to the questions about lessons learned in education for sustainability. This included their own emotions as motivations for teaching sustainability and in the process of teaching, as well as considering the emotions of their students (largely from the perspective of topic emotions; [2]). Thoughtful attention to emotions in engineering education has been recently emerging as a topic of research [3],[4], and these considerations may be particularly salient for sustainability education in engineering.

Background

Engineering education has traditionally operated under the premise that emotions are disruptive to rational thought processes [5]. This perspective, aligned with a culture valuing objectivity and analytical reasoning prevalent in STEM fields, has historically marginalized the role of emotions in educational settings [6]. Emotions, particularly negative ones, have often been viewed as hindrances to academic performance rather than integral components of the learning process [7].

Recent studies have begun to uncover the nuanced and multifaceted role of emotions in education, particularly in disciplines like engineering. Research indicates that emotions not only influence cognitive processes such as attention, memory, and decision-making [8], but they can also play a crucial role in shaping motivation and engagement with academic content [9]. Emotion researchers dating back to Darwin believe that "each emotion developed to solve a unique adaptive problem" [10]. Emotions in engineering education have been specifically explored in the context of ethics [11], [12] and future responsibility as engineers [13].

The culture of stress prevalent in engineering education [14], characterized by high academic demands and rigorous performance expectations, often gives rise to a spectrum of emotions among students and educators alike. While negative student emotions such as anxiety are commonly reported, they have been found to contribute positively to certain aspects of learning. For example, studies suggest that experiencing moderate levels of anxiety can lead to heightened accuracy, greater attention to detail, and more deliberate problem-solving strategies [15]. This paradoxical relationship between stress and performance underscores the need for a more nuanced understanding of how emotions impact learning outcomes in engineering education. It is also important to acknowledge that emotions and valences have different associations in Western compared to other global cultures [16], [17].

In the realm of sustainability education, emotions play a pivotal role in shaping attitudes and behaviors towards environmental issues [18], [19]. Related to climate change, Oberauer et al. [20] found that the negative emotions of anger, sadness, insecurity, and worry were associated with more complexity in student thinking about climate change, while other emotions (e.g., annoyed, hopeful) were associated with reduced complexity of their responses. A global study of 10,000 people aged 16–25 years indicated that 60% feel very or extremely worried about climate change, and 45% reported that such concerns affect their daily functioning [21]. Anxiety often occurs when people are confronted with uncertainty and threat, and when they perceive their own potential to cope with the threat as low [9]. Concepts like eco-anxiety have gained prominence, highlighting the emotional toll of grappling with existential environmental threats [22]. A 2017 report from the American Psychological Association defines eco-anxiety as the "chronic fear of environmental doom" [23]. Eco-anxiety encompasses a range of emotions from fear and guilt to despair and grief, reflecting a profound emotional response to the scale and urgency of global sustainability challenges.

The emotional landscape surrounding sustainability education extends beyond negative emotions to include positive emotional responses such as hope and empowerment. Hope is essential in enabling individuals to recognize both their capabilities and the opportunities available to them in a way that can help them engage in behavioral change (e.g. COM-B model [24]). Cultivating positive affective states can enhance creativity and resilience in addressing sustainability challenges [15],[25]. Positive emotions are also more likely to entice students to approach a topic and engage [26].

Intentionally considering emotions in the design of sustainability education in engineering presents an opportunity to foster a more holistic and effective learning environment. By acknowledging and leveraging the emotional dimensions of learning, educators can better support students in developing the emotional intelligence necessary to navigate complex real-world challenges. This approach aligns with broader educational goals of preparing future engineers with technical proficiency and the emotional resilience and ethical awareness needed to contribute meaningfully to society.

Several different emotional theories have been used to ground education-related research. In this work a discrete emotions framework was selected, followed by consideration of valence [27]. There are many different versions of discrete emotion theories which differ in both the number of emotions and specific emotion terms used. Several discrete emotions frameworks were explored for use in this work; those frameworks ranged from 6 to 48 discrete emotions [28][29]. The EARL / HUMAINE framework includes 48 emotions [28],[30]. Those emotions were "observed in naturalistic data" [28, p. 228], meaning that these emotions could be distinguished based on speech, non-verbal vocalizations, facial expressions, gaze, posture, and body movements. The 48 discrete emotions in the HUMAINE framework include 44 terms that the researchers identified in 4 or more reference sources plus 4 others. These 48 emotions are rooted in the 3 to 11 basic emotions, representing variations and mixtures of those basic or more 'hard wired' emotions [5]. The 48 emotions can also be viewed as a mixture of different dimensions, including valence (positive / negative), activation / arousal (low to high), power / control (personal or not), and novelty (low to high) [31].

This paper aims to contribute to our understanding of emotions during sustainability education in engineering. Instructor perspectives provide insights into their own emotions and those that they perceive in their students. It is hoped that increasing our awareness of emotions in sustainability education will improve the quality of sustainability education in engineering.

Research Questions

RQ1. What emotions do faculty describe associated with their sustainability education practices in engineering?
RQ2. Are the emotions associated with sustainability education in engineering more positive or negative?
RQ3. What are effective educational strategies in sustainability education in engineering that consider emotions?

Methods

This exploratory research is a post hoc study that was conducted using a set of transcripts from ten interviews with faculty who were considered front runners in integrating sustainability topics into courses for mechanical engineering students (for more information see [32]). The research was reviewed by the Institutional Review Board for Human Subjects Research at the University of Colorado Boulder (Protocol #22-0545).

The interviews were conducted in spring 2023 over Zoom and were each about 30-60 minutes in duration. The interview questions explored lessons they had learned teaching sustainability topics, suggestions for catalyzing other instructors in engineering to teach sustainability topics,

and factors that influenced their own sustainability teaching practices.

In this paper the instructors will be referred to by generic numbers (e.g., Faculty 1). The faculty members were teaching at universities in the U.S. (n=9) and Canada (n=1), were diverse in disciplinary backgrounds (mechanical, civil, materials engineering, non-engineering), gender identity (5 male, 4 female, 1 non-binary), teaching tenure (5 to over 25 years), and type of courses where they integrated sustainability topics (including required courses such as senior capstone design, first-year design, thermodynamics, heat transfer, and manufacturing, and electives including sustainable / renewable energy and others).

Following a discrete emotions framework, the 48 emotions described by Cowie et al. [30] were used as categories for deductive coding. Two raters looked for evidence of these emotions within each of the 10 interview transcripts. The emotions the faculty described for themselves and the emotions they perceived in their students were each noted separately. The coding necessarily included some level of judgment, given the similarity of some of the emotion words (e.g., anxiety and worry; powerlessness and helplessness) and because often the emotion related terms used by the interviewees were not discrete emotions within the framework (e.g., grumpy). In addition, sometimes the word used by the interviewee (e.g., love, fear) did not seem true to the emotion definitions given context clues. The two authors used a negotiated process to come to agreement on the coding. After coding into the 48 discrete emotions, these were grouped into the general valence categories of positive (24 emotions) and negative (24 emotions), following the literature conventions on valence categorization. Finally, the researchers focused attention on emotions that were discussed in the context of effective teaching approaches.

Limitations: During the interviews the faculty were not directly asked about emotions or the importance of emotions. Individual faculty may be more or less attuned to their own emotions, the emotions of their students, or comfortable discussing these emotions without explicit prompting. In particular, the perceptions of the faculty members being interviewed with respect to the emotions of their students might be incorrect. The identification of the 48 discrete emotions within the selected framework by the two authors may have included errors. Even within published literature the labeling of different emotions and boundaries of emotions are imprecise (e.g., nihilism in an affective versus purely cognitive sense [33]). The HUMAINE discrete emotions framework with 48 emotions distinguishes among similar emotions (e.g., pleasure, happiness, joy, delight) using an analysis of multiple verbal and visual cues, while this research only used the words of the instructors who were interviewed (and without specific follow-up questions to query emotions more deeply). We also acknowledge that this research only reflects the perspectives of 10 engineering educators in Western settings (the U.S. and Canada). Given the limitations of the study, the results should be considered preliminary findings to invite further in-depth research.

Results and Discussion

RQ1: Faculty and Student Emotions

The discrete emotions identified in the interviews are summarized in Table 1, indicating the number of the 10 interviews where the emotions were discussed in reference to instructors (personally, as faculty, from colleagues) or their students. The valence of these emotions (RQ2)

is also identified, listing the most commonly identified positive emotions first followed by negative emotions in order of decreasing occurrence. Emotions with a single respondent are not included in the table.

Table 1. Discrete Emotions associated with sustainability education in engineering and frequency associated with faculty and students among the 10 interviews (definitions from [34][35],[36])

Emotion	Definition and/or Example quote or idea from interview	# faculty	# students
+ Interest	engaged, fascinated, curious, wanting to investigate, become involved; "seems like a lot of students are interested"	7	8
+ Pleasure	enjoyment; "students enjoy it"	6	3
+ Hope	feel that desired event has possibility of happening	4	3
+ Excitement	you expect something good will happen	2	4
+ Joy	extreme gladness, delight; "it's joyful to be part of the human race"	3	1
+ Love	strong feelings of pleasure, commitment, and devotion	4	0
+ Satisfaction	something meets or exceeds your expectations	3	1
+ Trust	belief in truth of something or someone	1	3
+ Empathy	sensitivity to the feelings and experiences of others	1	2
+ Delight	great pleasure and happiness often accompanied by sense of satisfaction or contentment	2	0
+ Happiness	joy, gladness, satisfaction, and well-being	2	0
+ Courage	ability to meet difficult challenge despite personal risks	0	2
+ Pride	self-conscious emotion when one meets their goal and that achievement is recognized by others	2	0
- Fear	believe someone or something is dangerous or a threat; "you need to be able to go, 'That feels scary. How do I deal with my fear?'"	2	4
- Anxiety	unease about imminent event or something with an uncertain outcome; "keep students away from that doom and gloom perspective"	3	2
- Despair	losing hope; "without a view into ... what is possible in terms of human transformation it can be very nihilistic"	2	3
- Sadness	"the more you know the sadder the world around you gets"	3	1
- Frustration	upset or annoyed due to inability to achieve something; "this isn't just a nice course to have it is the future of the world we are talking about"	4	0
- Boredom	"in general [statics is] a little bit boring at times... [sustainability integration] can liven it up"	2	1
- Annoyance	annoyed that so difficult to get things done	2	0
- Stress	"no way we can solve everything at once, and I think that helps to allow students to relieve themselves of some of the stress..."	1	1
- Doubt	uncertainty or lack of conviction; "I don't really have a background..."	2	0
- Worry	worry about fate of the world for children and grandchildren	2	0

There were 13 of the 24 discrete positive emotions identified across all 10 interviews. The most common faculty emotions evident were faculty interest in sustainability and enjoyment (pleasure) teaching sustainability; similar emotions were attributed to students learning about sustainability issues. The faculty being interviewed were largely front-runners in integrating sustainability topics into their teaching and did so due to personal motivations rather than outside requirements (such as ABET accreditation). Thus, these emotions of interest and enjoyment are very congruent with this personal motivation.

A number of faculty stated that they enjoy teaching sustainability topics. Pleasure, happiness, joy, and delight were similar emotions that were somewhat hard to distinguish, most anchored in the word "enjoyment" from the interviewees. It has been stated that "to feel enjoyment is to feel satisfied with, or pleased about, one's participation" [37, p. 206]. In addition, Frenzel [9] mapped enjoyment to happiness. Sauter [38] discusses the need to disentangle positive emotions, noting the difficulty of this endeavor. The HUMAINE framework used to identify the discrete emotions used in this study interpreted emotions using facial expressions, body language, and tone of voice to distinguish among similar emotions; the current research only had audio recording to assist with identifying the most appropriate emotion label. Future research could ask follow-up questions to more accurately characterize the positive emotions that accompany this enjoyment.

The emotion of hope had several different facets. Faculty expressed hope that they could inspire their students to work toward sustainability. They also hoped to inspire other faculty to integrate sustainability topics into their teaching. Some also were hopeful that improvements in environmental and social conditions could be realized through engineers working collaboratively with other professions and individual efforts. Faculty also noted that they intentionally try to foster hope among their students, helping students see that a positive future is possible. This was contrasted with a concern that students would become hopeless about sustainability if given too much information on the lack of current quality of life for so many people worldwide and concerns around global climate change, resource depletion, and pollution.

While the emotion of love often has personal connotations, a few faculty used this term to describe their feelings related to sustainability education in engineering. Faculty 1 stated, "I love teaching it" in reference to sustainability topics in thermodynamics. Faculty 9 described loving the changes she saw in her students while teaching sustainability topics; "I love how they transform by understanding the culture." In these contexts, love is perhaps a less accurate emotional characterization than strong pleasure or joy.

The 48 emotions in the framework used in this study seemed incomplete. For example, the feelings of gratitude / thankfulness identified by two of the interviewees have been included in other discrete emotions studies [39] but were not among the 48 discrete emotions identified by Cowie et al. [30].

On the side of negative emotions, there were 16 among the 24 discrete emotions identified. The most common were despair and anxiety. For example, two interviewees used the term "doom and gloom" in reference to their own feelings and their perceptions of the feelings of their students with respect to the (un)sustainability of the planet; these feelings seem to be best characterized as despair, anxiety, and/or fear (three discrete emotions within the coding framework). These emotions are aligned with earlier studies that found eco-anxiety. The feeling

of sadness also aligns with these feelings.

Some faculty evidenced frustration, largely associated with their negative emotions associated with dealing with administration or some other faculty. Some of the interviewees were frustrated that others didn't feel that it was important to teach engineering students about sustainability. The emotion of boredom was found largely when faculty talked about avoiding boredom for themselves or their students by incorporating current events and interesting information about sustainability. This contrasted to decontextualized ways of teaching fundamental engineering principles, such as was typical in statics, for example.

There were small numbers of references to other emotions. Just two for annoy, doubt, shock, stress, and worry. These emotions are actually very similar to anxiety (stress) and fear (worry) which were believed to more accurately reflect the sentiments described in the interviews. There were only single instances where anger, disappointment, disgust, guilt, irritation, and shame were implied in the interviews.

RQ2. Valence of Emotions

The number and valence of the different emotions of instructors and students that were identified in each of the 10 transcripts are shown in Figure 1. Per interview the number of distinct discrete emotions ranged from 3 to 13 for faculty and 1 to 14 in their students. Some faculty used much more emotional language in their interviews (e.g., Faculty 3, Faculty 6) than others (e.g., Faculty 2, Faculty 8). The 4 faculty with very little discussion that was interpreted as relating to emotions align with the traditional notion that "emotions are not typically addressed or valued in engineering" [40]. In nine of the ten interviews more emotions were identified that related to instructors (usually themselves, occasionally referencing other instructors in their programs) than in students. This seems logical as the instructors might feel more comfortable revealing their own emotions but hesitate to speculate on the emotions of their students. Further, the faculty may have different levels of emotional intelligence and thus are more or less attuned to perceiving emotions in their students [4].

Considering the valence of the emotions, three interviewees only described positive emotions, three included more distinct positive than negative emotions, and four had more distinct negative than positive emotions. With respect to emotions inferred for their students, in six interviews only positive emotions were evident; in five of these individuals the positive faculty emotions also outnumbered the negative faculty emotions. There were also two interviewees where the number of distinct positive emotions was equal to the number of distinct negative emotions, and two interviewees with more negative than positive emotions. Except for Faculty 4, interviewees who described a larger number of different emotions included more negative than positive emotions. It seems important to be attuned to both the positive and negative emotions that can accompany considerations of sustainability in engineering.

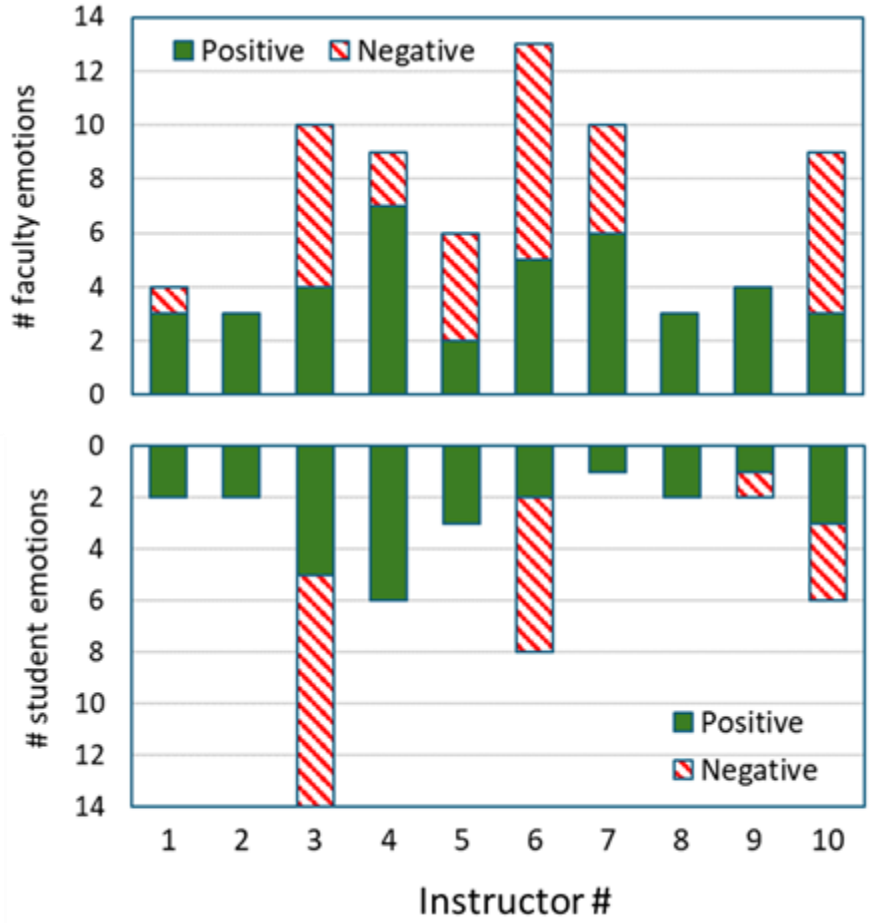

Figure 1. Number of different discrete emotions counted in each of the 10 instructor interviews that were attributed to faculty or students and grouped into positive and negative valence.

RQ3. Teaching Strategies

There were a variety of teaching strategies for sustainability education in engineering that relate to emotions. These strategies include role modeling, mindfulness, helping students imagine small tangible contributions, fostering positive emotions like fun and hope, and avoiding doom and gloom. Specific examples of these ideas are described below and summarized in Table 2.

Table 2. Summary of ideas for teaching

Type of strategy	Examples
Role modeling	• Share your own emotions about sustainability issues (can include fears) • Take a hopeful tone (e.g., share positive trends [41])
Mindfulness	• Assign reflections • Class discussion
Small contributions	• Reinforce students don't need to solve the whole problem alone
Fun	• Games (e.g., Megawatt card game; In the Loop) • Build and race RC cars (include points for reusing materials; reflection)
Interest	• Projects (e.g., off grid solar project) • How things are made associated with hobbies, sports (e.g., Legos) • Current events (e.g., inflation, Ukraine) and quotes (discuss agree / disagree) • Historical perspectives (e.g., Legos, Light Bulb Conspiracy)

One interviewee with over 25 years of teaching experience across two different universities asserted, “The biggest lesson for me was that [sustainability] has an emotional profile which you cannot disregard. …. some students changed their lives …. account for that …. You are giving people a look into the future and it really is scary. It can be scary …. [sustainability] is not just cognitive …. it is their futures and the life that they imagine for themselves …. Awakening can precipitate an existential crisis …. when you really look at the science, nihilistic.” This faculty member came to understand that their enculturation in engineering cut them off from intuition, and it has been a journey to acknowledge their emotions of anger and fear around sustainability topics. They **role-modeled** for students the capacity to feel, bringing **mindfulness practices** into their courses. “What are the implications? I try to make sure we don’t ignore those externalities and also cultivate the embodied capacity to feel. .... The whole person in this, right? Yeah, it's strangely new to people.” Note that while historically many faculty needed to spend time drawing students’ attention to concerns about unsustainable practices, today’s students seem at least generally aware of sustainability-related issues (e.g., climate change).

Another faculty member who first started teaching sustainability related topics in a first-year engineering course about 20 years ago spoke of intentionally trying to pick something that is **optimistic and hopeful**. They tried to avoid their natural tendency toward doom and gloom in order to motivate students with positive emotions and feelings that they can help and contribute to benefit the planet and people.

To combat stress, an additional faculty member with over 10 years of experience integrating sustainability topics into a variety of courses described two lessons. The lessons followed a statement that “sustainability is huge”. The first lesson is “all I can do is teach a few things and hopefully get some students interested.” Here, the instructor is trying to activate the positive emotion of interest among students. The second lesson is to teach the students that “this is a really big puzzle of which **all of us has a piece** … there’s no way we can solve… everything at once. And I think that that helps to allow students to relieve themselves of the stress of this idea of it.” This message helps students to overcome being paralyzed by the daunting scope of world problems. It may help reduce students’ stress and doubts associated with feeling responsible for such a huge problem, helping them find courage and hope. Contending with concern and/or doubt of the ability to incorporate sustainability into technical core engineering courses, this faculty gave an example of applying the technical calculations to a sustainability related problem and then making this an opportunity to have a discussion regarding sustainability. The example was from a Statics course and when the students design and technically evaluate a canopy, instead of putting a random weight on the canopy, the students design the canopy to hold a specified number of solar panels. The students perform the technical calculations and the faculty then uses the opportunity to open up a discussion on energy production and various pros and cons. “We talk to students about things like, what is the real reason we're doing this? They're like, Hmm, greed…for consumerism. .... I always tell my students don't shy away from that conversation. ... That conversation is really important.”

Another professor with 23 years of teaching experience leaned into the elements of making learning **interesting and fun**. He shared a number of different examples of the activities that bring sustainability to life for the students, many in the context of a first-year introduction to engineering course. An extended quote from the interview is provided below.

> We use a **game** called In the Loop [42]. It was developed in Europe. It's a game where you're a manufacturer, manufacturing various products, and then there's rare earth elements around the outside. You have to mine those and then produce your product. There is limited availability of things and cost, and then it's you get advantages for doing circular economy strategies. You can set up ways to recycle. And there's different strategy cards you can employ. The students play that game, and it's a very engaging game. And afterwards we have them reflect on their personal impact environmentally, how you can design for recyclability or repair-ability. So it's dealing with issues of personal ethics within that context of environmental impact. They **enjoy playing the game**, but the reflection piece is where it gets a little deeper for the students. ... some students just sort of fill out a required reflection, but others it really profoundly effects. ....
>
> Then we do another **project** which sort of leans into that as well. They're building little RC cars for a competition out on our running track, and one of the performance criteria they're evaluated on is their cost that is reusable. We start the project with a parts auction. And so we auction off parts from previous vehicles that are reusable. It's mostly motors and wheels but they can earn credit. So if they don't modify it, they don't damage it, and it can be taken off. So don't epoxy your motor to the vehicle. If it is unaltered, then you can get credit back against your cost for that reusable cost as part of the evaluation criteria. .... and we talk about the vehicles as electric vehicles....
>
> [In] a **card game** called Megawatt.... you're designing a grid ... trying to produce power, and you get penalties for environmental impact. ... it's sort of a strategic game where you can choose to load up on coal but then that has a high environmental impact. The students again reflect on that afterwards and think about what are the implications? .... They start to realize that it's not so easy to move away from some of the fossil fuels sometimes. Some of the more environmentally minded students will grudgingly see the value of some nuclear capacity for achieving their production needs. It's interesting the reflections that students have coming out of that game because it does a pretty good job of modeling realities.
>
> [In an] **Off-grid Solar Project**... one of the best parts about that was requiring the students to propose energy usage for a home that they're going to have to power with batteries. They always start with 'I need air conditioning, and I need a washer and dryer', and blah blah blah. And then they realize that they need to spend $40,000 on batteries that will wear out in 5 years. And that's too much. And so then they start thinking about **needs versus wants** in terms of power consumption. We do that with more of a personal energy audit. And they need to propose an American home with a lifestyle that could reduce the electrical consumption by ... a 50% reduction. Can you imagine living in this house with 50% less electricity? And how would you get there. ....
>
> ... the final exam... is similar to the **Model UN**. They're all assigned roles and then we have a model town hall where someone is maybe proposing a wind farm adjacent to the town. ... folks are pro and against, and they have to argue their cases to the leadership of the town.
>
> Yeah, it's fun, and **they enjoy those activities, they love them**.

He strongly believed in the value of balancing fun with a **reflective component** for students. Often the 'profound effects' with regards to student engagement with sustainability came when

reflecting after the fun activity. Although not specified by the professor, the prompts for student reflections can help students connect with their emotions (e.g., [43]).

Another instructor shared examples of interesting ways to integrate sustainability topics into upper division courses. An extended quote from their interview is provided below.

> The [manufacturing processes and systems class] I think is really fun. …every semester things have changed, and the content really motivates itself. .... I think generally even people who aren't engineers tend to be interested in **how things are made**. And so I think it's a really fun class to bridge all these gaps and say, you might be interested in this already but now let me take a more engineering approach to it, like you see a lot of details about systems and details, about optimization and efficiency, but also about the people behind making everything. So one of the takeaways for my class is always, you know that the textbook will give you this clear diagram. It's like, oh, this is the manufacturing process, and this is the system that helps coordinate everything. But don't forget that there's actually people at every one of these steps. That's what actually makes everything go. So that's one of the themes of the course in some ways.
>
> [A lesson learned in teaching sustainability topics is to] keep it **interwoven** rather than have a week on sustainability. [In the manufacturing course] even if we don't [explicitly] talk about sustainability it's kind of always in there. I think a really interesting thing is to get students some **historical perspectives**. .... I also think, in general, our students are much more aware of life cycle impacts and very much like climate change. And I don't know if that's because of their age, or because they are choosing to come to school here, but I think they really do get it. And so we talk about that. We talk about it in the context of Legos.
>
> .... **Legos** have been really fun teaching examples, because in manufacturing they're known as a really precise process. And they're known for really good process control for the longest time. They're claiming any brick that is made today, any place in the world can still stick together with a brick that was made anywhere in the world all the way back to 1958. I share that with the students. I downloaded all these company reports from Lego in 2017 and 2015, and in those days Lego was still celebrating we make this many billions of bricks every year. They have stats that are like there's enough Lego bricks for every human in the world to have like a 100. They make so many bricks you can circle the sun so many times. They used to brag about their proliferation, but I think they very quickly realized these savvy consumers also understand that those bricks are never going anywhere, right? They're never biodegrading. They're made of the hardest, most chemically resistant plastic that there is. So should we really be celebrating when they make like a billion more every year? At what point is it like don't we have enough? So they really shifted their whole corporate narrative now to talk about sustainable materials. And so it's really fun, I think, to connect that because students usually have [had] such tangible experiences with Legos. And to say, you have to understand why Legos are manufactured the way that they are. What does it mean to be able to process control them that precisely? What does it mean for them to shift their entire manufacturing model to use sustainable materials? And then we get into these conversations like, what does that even mean? Because they're not going to be able to make recycled Legos. They're saying they're starting with a different kind of plastic that's sugar cane based instead of petroleum based. And that's why it's renewable and we talk about that.

> And then they use that example throughout a bunch of different units. And then they analyze a lot of different perspectives which then includes some understanding, I think, of what would it mean for this product to be sustainable. And so we talk about it in that context, … we talk about waste and recycling and read articles about [it]. …. They have a reading assignment that goes with pretty much every homework. And it tends to try to be like modern applications, or **modern challenges**. And again, since it's **in the news** so much there's a lot to talk about. …. Yeah, stuff all comes from somewhere. Final projects… a lot of them do have some sustainability focus, or they're motivated because of inflation, right, and just why does this cost so much now? And I also think that it's just important to tie together these concepts. Yeah, engineering is involved with economics. Like, oh, yeah, this does matter. And on a global scale. And I think it's really cool for them to see these Geopolitics. Some students did projects one semester about different cooking oils, and there's a shortage there because Ukraine produces a bunch of cooking oil….

> In the Design for Inclusion class we talk more specifically, I guess, about sustainability. And again, it's sort of in the history of engineering itself. We watched a documentary called the **Light Bulb Conspiracy** and it really discusses the **concept of planned obsolescence**. It unveils this whole great story [about] a cartel of light bulb manufacturers that decided that the lifetime of a light bulb should be 1,000 hours. And before then it was actually unlimited. And so they have this famous firehouse in California somewhere that has a lightbulb that has been on for over a 100 years. At one point this was the expectation for light bulbs. But then someone realized, then we can't sell that many. …. {more examples with plastics, expensive…} Who chose what engineering is, what's there and not fair to be included. If you're not going to take responsibility for this then who is? ….

The instructors often leaned into **current events** of interest to the students. Centering the student experience sparked interest and allowed them to consider their personal position and feelings.

> I'm a really big fan of **popular education**. So I try to start from the student experience as much as possible. So, rather than presenting things to them, I do an **activity** where I show them quotes and then they have to disagree or agree with it. And that kind of leads to a nice conversation about different aspects of sustainability, or where people might disagree, you know, and how the social aspects fit in with the environmental. And trying to understand people who aren't as much in favor of sustainability, and where they're coming from. So it kind of brings in the social political aspect to the thinking around sustainability. That's kind of a fun one.

The above examples showed different ways that instructors integrated sustainability into their courses, providing activities and assignments largely designed to provide real-world context, spark student interest, and understand the complex interactions among social, environmental, and economic impacts. The majority of these teaching approaches used student centered pedagogies, including projects, activities, games, class discussions, and personal reflection.

Conclusions

In this research we considered the emotions that are relevant when teaching engineering students about sustainability. Many of the faculty among the small group of early adopters that we interviewed considered student emotions in their teaching practices. Sustainability topics often can bring up negative emotions due to the daunting global environmental, social, and economic

issues that are currently pervasive. Many engineering students may already be stressed and anxious about climate change and other sustainability issues. Some faculty recommended acknowledging these concerns and then leaning into what part we can play as individuals and future engineers in making things better. There were also many examples of the fact that most students do need to be made more aware of the complex interconnected environmental, social, and economic elements that should be considered. Our problems extend far beyond our carbon footprint to other air pollutants, water contamination, natural resources, the biosphere, and complex geopolitical, cultural, and ethical issues. In the face of these weighty concerns, most faculty still found ways to bring interest, fun, and hope into sustainability topics. Most of the sustainability teaching examples were more than calculations (e.g., carbon footprint), integrating personal reflection and interactive discussion elements.

Beyond considering the emotions of our students, individuals should take the time to reflect on their own emotions in the process. We are likely to be grappling with our own frustrations and worries. Many of us also find sustainability topics extremely interesting. We can share our emotions with our students, working against the dehumanization which sometimes accompanies engineering education. We can be role models for students that it is okay to feel emotions as engineers. We can acknowledge our concerns and also share reasons to be hopeful. There has been positive progress in many areas [41]. While some of us may feel isolated in teaching sustainability within our local context, we can come together with other educators who are passionate about sustainability topics to learn together. For example, the *Engineering for One Planet* initiative is working to build this community [44].

In future work the continued diffusion of the 'innovation' of integrating sustainability education into engineering courses should more explicitly research the emotions of the course instructors and students. Engineering can learn from other disciplines who are ahead in education for sustainability. The U.S. is also not a global front-runner in education for sustainability and should seek models from abroad. Working together we can achieve a vision where every student who graduates with a degree in engineering feels a responsibility to strive toward sustainability and is equipped with the mindset, knowledge, and attitudes to achieve this goal.

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