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An Ecofeminist Grounded Analysis of Sustainability in Engineering Education: Skill Set, Discipline, and Value*

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Sustainable engineering has been highlighted in many national reports as a key component of the education of engineers of the future. Yet faculty perceptions of sustainable engineering as 'soft' and outside the boundaries of engineering prevent its widespread inclusion in the engineering undergraduate curriculum. In this paper, we demonstrate how ecofeminist theory could be used to understand the inferior status that sustainable engineering currently occupies in the disciplinary hierarchy. To characterize the ongoing debates and tensions underlying acceptance of sustainability as part of the engineering process as well as of engineering education, we have closely analyzed 42 out of 150 articles published in the area of engineering education using inductive grounded theory, and we relate our themes and sub-themes to ecofeminist theory. The first theme considers sustainability to be a challenging skill set for the future engineer; the second emphasizes the disciplinary aspects of sustainability; and the third theme looks at the normative aspect of sustainability as value-based engineering. We found it helpful to use ecofeminism as a framework for thinking how sustainability's marginalization in engineering education could be related to its 'soft' ness, its chaotic and system-level character, as these aspects align it not with the core of engineering but rather with the marginalized 'feminine.' This framing should help us reconceptualize how we talk about sustainability in engineering education to make it a more integrated and valued concept for future engineering students.

Keywords: sustainability; sustainability education; grounded theory; literature analysis; content analysis

1. Introduction

Sustainable engineering is considered by some to be a critical part of the education of future engineers [1]. However, the process of defining sustainability is fraught with debate, leading to a number of issues negatively affecting its effective use in education [2]. In addition, Moore [3] highlights a number of barriers to the effective implementation of sustainability programs in university courses, beginning with disciplinary environment.

The current disciplinary divisions in academia can create 'silos' of isolation, with little potential for new ideas and courses to be included in the space of prerequisite coursework. One of this paper's authors has claimed that the idea of disciplines is a form of boundary work that 'prompts ideas of inclusion and exclusion,' suggesting that academic engineers (such as engineering faculty members) define actions, events, tasks, or content as 'acceptably engineering' or reject them as 'not engineering' [4, p. 5]. It is at this boundary of engineering and non-engineering that sustainable engineering seems to exist, which prompts some to question its inclusion in an already overloaded engineering curriculum [see 1]. But when engineering faculty members express strong opposition to sustainability, they decrease the value that students place on sustainability in engineering design, and discourage students from considering any course addressing sustainability [1]. This debate on how sustainability relates to engineering education is quite animated [3, 5–7] although it often gets sidetracked by the broader issue of lack of a consensus on the mechanisms of sustainability [8]. Through this study, we summarize the underlying tensions on the value placed on sustainable engineering within the broader engineering education community. We then look at the tensions and debates surrounding the question of whether 'green' or 'sustainable' engineering is 'real engineering.' As a corollary to the debate, then, is how sustainable engineering may be treated as a core versus marginalized part of an engineering curriculum. Two research questions that have guided our larger research project are: 1) How does the call for sustainability in engineering education affect the boundaries of what 'engineering' is? And 2) what are the broader discourses about what engineers should be doing (not restricted to sustainability)?

We begin this paper describing a theoretical approach we have found helpful for thinking about these two questions: that of ecofeminist theory. We situate this theoretical approach in the context of some scholars' conceptualization of sustainable engineering in embedded engineering systems, and with our previous call to 'normalize' sustainability in the engineering curriculum. We

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then outline our research design and analysis, and describe and discuss our results of this design. We end with some implications for engineering education.

2. Theoretical framework

Because of the research team's interdisciplinary experience (encompassing engineering education, environmental science, women's studies and communication), after doing an initial review of engineering education literature, we realized the potential for using an ecofeminist theoretical framework in tandem with Corbin and Strauss' [9] grounded theory method to understand sustainability in engineering education. Corbin and Strauss [9] describe grounded theory as a qualitative research method that involves analysing text, interviews, and ethnographic data inductively, an analytic process of making comparisons to highlight similarities and differences. Researchers first look for concepts within small sections of data that they later categorize into larger 'buckets' or higher-level categories. This section describes both these theoretical approaches in the context of our work.

2.1 The ecofeminist approach

Mack-Canty [10] situates ecofeminism within third wave feminist approaches. Third wave feminism, according to Mack-Canty, 'refutes dualistic thinking that divides the world into hierarchical dichotomies with one aspect regarded as superior and the 'other' as inferior' [10, p. 158]. Third wave feminism recognizes multiplicities and intersectionalities, where intersectionality is the idea that to understand people's lived experiences one must take into account the intersection of their social identities rather than focusing simply on one (such as looking at race, class and gender together when considering women's underrepresentation in engineering) [11]. Ecofeminist theory, making use of this idea of multiplicity, insists that non-human nature is a feminist concern, uniting the principles of ecology (interdependence and diversity of life forms) and feminism (intersection of oppression of women, racism, colonialism, classism, heterosexism etc.), resulting in efforts to create 'equitable and environmentally sound lifestyles' [10, p. 169]. Ecofeminist approaches, similar to other feminist approaches, have their roots in activism and seek to bring about different forms of social change, including more overt changes (as in policy) or more subtle changes (as in perspective [3]). The next section discusses parallel thought processes in sustainable engineering that resonate with this preliminary discussion on ecofeminism; we discuss ecofeminist philosophies in greater depth in Section 2.4.

2.2 Sustainable engineering: embedded systems

Allen and Shonnard [12] emphasize that engineers who practise in the 21st century will have to focus on developing new technologies that address current societal needs while also understanding of the limits of natural resources and protection of environmental systems for future generations [13]. Sustainable engineering is thus the practice of engineering with a deeper understanding of the environmental, economic, and social systems in which technology is embedded. Proponents of sustainable engineering emphasize the crucial need for systems thinking. Vanasupa et al. [14] echo Gaylord Nelson by positing that the relationships between society, economy, and environment view these three systems as embedded systems: the environment is the system in which society entirely resides; and the economy is a wholly owned system within society. In a similar vein, at the human level, Bonnett [2] argues that nature may be independent of human beings, yet the actions of humans have an impact on nature. It is this connection with nature, Bonnett argues, that is often overlooked by engineers and engineering educators in the solving of technical problems.

We propose that, just as production, consumption, and other processes that occur within the economy and society are embedded in nature [14], the concept of interconnectedness in ecofeminist philosophy allows us to see how technology and society are not different or separate from nature. Indeed, humanity is 'embodied' in nature, although this seems to be in direct conflict with the idea of 'objectivity' or the process of distancing oneself from one's surroundings. In acknowledging our embeddedness, perspectives on sustainability echo the sentiments of ecofeminism and position themselves in opposition to the proponents of objectivity who are often found among traditional engineers.

While we acknowledge that the idea of 'embeddedness' may invoke a sense of hierarchy in which the embedded is dominated, the 'direction' of hierarchy is perhaps open to debate. Thus we could argue, as Vanasupa et al. [14] do, that nature embeds society, which in turn embeds economic production. Alternatively, we could argue, as Williams [15] does, that technology today attempts to embed nature, detaching human beings from nature, reversing the old order of nature sustaining humans in a direct manner.

2.3 Sustainability is chaotic and has shifting boundaries that may place it outside engineering silos

A number of scholars have discussed extensively that the concept of 'sustainability' itself is problematic, including that it is broad and complex [16], that it defies the boundaries of academic discipline [3], and that it has no measurable characteristics [1]. Allenby et al. [8] point out that sustainability has characteristics of almost mystical proportions that completely escape the measurable and quantifiable realm in which traditional engineers tend to work. And yet sustainability is an important part of the process of engineering, particularly engineering design [1, 7], that is being disregarded by many industries in lieu of more immediately measurable goals, such as efficiency or short-term profit [17].

These points engage our ecofeminism argument. Warren [18] has argued that measurable characteristics such as 'efficiency' and 'output' are adjectives that describe masculinity (see Warren's description of linguistic interconnections in [18, p. 28]). Sustainability, in contrast, has been described as 'mystical' [18] 'without discipline', 'broad', and a 'soft' skill, all of which are terms often used to denigrate the feminine [18, p. 28].

We propose that, in identifying sustainability with adjectives used to denigrate the feminine while using masculine adjectives to describe the work of engineers, sustainability is 'othered' from engineering. The perception that sustainability is 'soft' and thus not something in which a (masculinized) engineer would engage, again is a dualism with a hierarchy where the traditional masculinized engineer occupies a highly valued position, while the devalued feminine/feminized sustainability is relegated to the outside of engineering. As a consequence, perhaps, projects within traditional engineering that are focused on short-term profit making may get more resources while long-term sustainability oriented projects may be allocated fewer resources. To get a better sense of how sustainability gets marginalized from engineering, we can learn from ecofeminism.

2.4 Ecofeminism and sustainability

The term ecofeminism is attributed to Francoise d'Eubonne's 1974 work '*Le féminisme ou la mort*' [18–20], where she presented the fundamental ideas combining the principles of ecology and feminism. The main premise of ecology that ecofeminism borrows is that all organisms are interdependent, which, in the context of the relationship between human beings and nature, emphasizes that human beings are linked inextricably to and embedded deeply within nature rather than apart from it. Every human action therefore has consequences that not only affect other human beings but also the natural environment. This is in stark contrast with the idea that nature exists for the purposes of serving humankind, a perspective termed as 'anthrocentrism' [18–20]. Ecofeminist works emphasize the existence of dualisms [10] or splits [21] that, in essence, artificially distance humans from nature, labeling nature an 'other' in contrast with the humans as self or center. The feminist perspective within ecofeminism draws upon conceptual parallels between the domination of nature by humankind and the domination of the feminine by patriarchial thinking. In their classic work *Ecofeminism*, Mies and Shiva [22] emphasize that the claims made by practitioners of science of objectivity and being value free are false as they privilege the ontology (the belief systems about what is/are truth/s) and epistemology (how we know truth/s) of a predominantly masculine perspective. In contrast they emphasize that alternate ways of knowing that stem from nature, in most cases associated with women and members of non-mainstream communities are delegitimized and marginalized.

To change thought processes in engineering, our study seeks to increase awareness about the inherent 'othering' of sustainable engineering within academic engineering disciplines. Through the common practice of differentiating between 'hard' and 'soft' disciplines (with the problematic overtones of 'hard' and 'soft'), scholars have noted that sustainability has been labeled a 'soft' (and therefore easy and unimportant) discipline [16, 23]. Brawner et al. [23] have noted that 'soft' disciplines, in contrast with 'hard' disciplines, are identified with such characteristics as 'distance from technology,' a lower likelihood of using graphs, and a less positivist theoretical perspective, in contrast with a more traditional engineering perspective. This practice situates sustainability as inferior to traditional engineering, and therefore qualifies as 'othering' sustainability. In social theory, this 'othering' is understood within feminist scholarship [24–25] as the tendency by a dominant group to marginalize or sideline minority groups either through explicit practices or implicitly in day-to-day practices. As an example of overt 'othering' in the context of women's underrepresentation in engineering, there are numerous historical cases of women being explicitly prevented from applying to engineering programs [26] as they were not considered appropriate potential engineers—these women were 'othered.' Othering is more subtle today when undergraduate engineering classes contain mostly male students, thus generating classroom discussion that may be more relevant to male engineers.

If we note that engineering has had a history as having in-groups and out-groups [26–28] where women and the feminine have systematically been othered [29], this becomes a feminist discussion. The 'othering' of sustainability therefore can be considered an ecofeminist discussion, as can the idea of sustainable development with its focus on equitable distribution of resources. Feminist researchers have emphasized the need to look within academia to question prevalent power structures [3]; our choice of looking at articles within engineering education journals addresses that need.

Next, we explore ecofeminist philosophy and how it applies to our thinking about the teaching of sustainable engineering. We begin by exploring key ideas related to ecofeminism, then identify aspects of sustainable engineering that are discussed extensively in engineering education literature and connect the two.

2.5 Dualisms, hierarchies and interconnectedness

Mack-Canty [10] argues that we are in a third wave of feminism, which begins with the situated and embodied perspectives of women who are different and have been differentiated against by the dualistic hierarchies, rather than the largely white, middle class concerns of second wave feminism that preceded it. (First wave feminism is considered to be about women's right to vote; the second wave is considered the US Women's Movement in the 1970s.) Among many other key theoretical advances, third wave feminism deconstructs the notion of duality, an idea central to many forms of Western thought where there is a supposed disconnect between the public and private, male and female, and culture and nature. On one side of the duality is the public, the masculine, and culture, and at the other end we find the private, the feminine, and nature. As Mack-Canty [10] and others have argued, culture (and by extension the male) is said to be endowed with 'disembodied' characteristics such as order, freedom, light, and reason, while nature (and therefore the female) has 'embodied' characteristics such as disorder, physical necessity, darkness, etc. Zimmerman [21] argues that this split between humanity and nature is hierarchical in nature, a dualistic hierarchy where the private/nature/feminine is dominated by the more valuable public/culture/masculine [20], giving the former more access to resources both natural and human made over the latter.

To connect this more closely with engineering and technology, we draw upon the work of Rosalind Williams, a historian at Massachusetts Institute of Technology. Williams [15] notes that human beings have long used technology to dominate nature for their own needs:

> Human beings have always tried to control nature so as to make life safer, more predictable, more abundant and more fulfilling. But since the beginning of recorded history, non-human nature has been the ground of human life. This relationship between technology and nature, between figure and ground, which had been reversing slowly over centuries, reversed decisively in the past century. The built world has become the ground of human existence, now framing and embedding non-human nature. We have gone from using technology to control and exploit our habitat to using it to detach ourselves from our habitat. (p. 23)

While Williams does not directly engage in or with ecofeminist work, her point provides historical perspective to the claims of ecofeminists. The idea that human beings have increasingly through history tried to control nature resonates with the idea of hierarchies, with nature subjugated by humans. Williams emphasizes that, while people in the past may have seen themselves embedded in non-human nature, human technology today attempts to control that non-human nature. She calls for a different relationship with nature, noting that we live in a '*hybrid world*' where nature and humans are inextricably linked, therefore requiring an awareness of the long-term social repercussions of technology.

Besthorn and Pierson-McMillen [19] identify three conceptual themes running through literature on ecofeminist philosophy. The first one involves connecting the problematic split between humanity and nature to the split between male and female, which is supported by a dualistic power hierarchy that creates a logic of oppression. Their second theme is the conviction that the human/nature relationship and all similar forms of domination are feminist concerns. The third theme refers to interconnectedness, or the perspective that all things, both natural and human made, are connected in communal networks that we choose to ignore in our current pursuit of modernized objective knowledge.

Warren [18] presents a Western philosophical perspective on ecofeminism, connecting the domination of women, children, people of color, and the poor to domination of nature. Warren, echoing a broader ecofeminist perspective, argues that nature is a feminist concern and that understanding the domination of other groups of human beings helps understand the domination of non-human nature. She uses an example of water scarcity to demonstrate this idea. In many water-scarce countries in Africa, Asia and Latin America, it is primarily women and children who collect water, many having to walk ever increasing distances to do so [18]. Therefore water scarcity is a natural resource issue that directly affects the lives of women and children. We can expand this relationship by looking at waste disposal into water sources; the pollution of rivers has an immediate effect on women and children collecting water who have close contact with the polluted water.

Warren [18] recognizes that ecofeminism refers to a variety of perspectives on the domination of nature, which have historical, conceptual, empirical, socioeconomic, linguistic, symbolic and literary, spiritual and religious, epistemological, political, and ethical properties. While we seek to understand a diversity of ecofeminist perspectives, we have described mainly two here. Within the historical perspective, ecofeminists suggest that androcentrism (male-centered thinking) is the root cause of environmental destruction. The conceptual argument emphasizes that the focus on rationality (argued to be a patriarchal and oppressive framework) distances one's self from nature, mediated by the logic of domination. In the socioeconomic argument, Warren [18] maintains that, just as women's bodies and labor are colonized by capitalism and patriarchy, nature too is dominated by capitalist and patriarchial forces. Similarly, Mies and Shiva [22] make a strong statement against the reductionist tendencies of science by emphasizing that science is not value neutral as it privileges positivist scientific and technological ways of knowing (socially connected to masculinity) and necessitates subjugation of the natural (inferred as femininity, and seen as separate from science and technology). Warren's [18] and Mies and Shiva's [22] perspectives, however, tend to contribute to the dualisms in pitting the masculine against the feminine, and technology against nature. These dualisms then contribute to unintended side effects for the same women that the scholars actually set out to support. We therefore believe in Mack-Canty's [10] call for re-weaving these masculine/feminine, in-group out group, hard/soft, dualisms and approach sustainability as a normal part of engineering.

2.6 Normalizing sustainability by re-weaving dualities

Elsewhere we have proposed teaching undergraduate students about sustainability as a 'normal' and 'standard' part of engineering rather than as an 'add-on' concept [30]. This 'normalized' sustainability as a normal part of engineering design is, in a sense, a re-weaving of the hierarchical dualisms [10] of the masculinized traditional engineering and the feminized sustainable engineering. Our reframing of sustainable engineering acts to reform the engineering process through the education of students, with sustainability ultimately becoming part of the fabric of their professional engineering mindsets [3] rather than as a constraint imposed by legal and political stakeholders. The idea is that the contemporary engineer must be trained to focus not only on the immediate problem at hand but also the broader impact on the environment, given that all things are interconnected [7].

So far, we have explored aspects of ecofeminist philosophy that we consider relevant to sustainable engineering. The idea of interconnectedness in ecofeminism resonates with the notion of embeddedness in sustainable engineering, and emphasizes that human activity is embedded in a natural environment, where all things within and outside that environment are interconnected. Thus, given this embeddedness and interconnectedness, engineers need to have a broader conception of the repercussions of their actions. This perspective is different from the traditional engineering perspective, one in which engineering design and, in essence, the masculinized human activities of high efficiency, are separate from or external to nature. We have also explored the ideas that a hierarchical dualism exists in the realm of traditional engineering that relegates the feminized concept of sustainability to the margins, while valuing measurable characteristics such as efficiency and output in the design and production process leading to products that may seem attractive in the short term but that are ecologically detrimental in the long term.

We have outlined a theoretical framework of ecofeminism, connected it to aspects of engineering design, and argued its relevance to the marginalization of sustainability in engineering contexts. In the next section, we describe our research design to which we apply this framework, and summarize Corbin and Strauss' [9] grounded theory method that we used to analyze a set of articles on sustainability in engineering education.

3. Research design

This work involved searching for articles related to sustainability and engineering education in the peer-reviewed archival literature, then analyzing the resulting database of 150 articles using grounded theory. Through the analysis, we generated themes related to how sustainability is described in engineering education journal writings.

Using the search terms 'sustainab*' and 'engineering,' in the years between 2000 and 2010 we collected 150 relevant articles identified from key journals in engineering education and sustainability education including the *International Journal of Engineering Education, European Journal of Engineering Education*, and *International Journal of Sustainability in Higher Education.* We conducted the search using the *Web of Science* library database, which contains full-text articles from a wide range of science and engineering journals. We were specifically looking for articles within engineering and higher education that included sustainability in some way or form, including 'sustainable,' 'sustainability' and other terms. We therefore searched using the terms 'sustainab*' and 'engineering'. We noted that the flagship engineering education journal, the *Journal of Engineering Education*, did not publish any papers using these search terms. This absence is significant and lamentable, given that engineering educators have long called for the inclusion of sustainability in engineering education courses [1].

We coded a total of 42 articles before we observed that we had reached a level of saturation. Of the 42 articles, five were research studies, 19 were position statements, 10 were course-level intervention descriptions, and eight were program-level intervention descriptions. Course-level interventions looked at changes made to a specific course, for example, the introduction of a new sustainability-focused final project within a course. Program-level interventions focused on changes made to a curriculum, such as the introduction of sustainable engineering modules within and across courses in a degree program.

We employed grounded theory to analyze our data: research papers relating to sustainability and engineering in education. Grounded theory provides researchers with the flexibility to develop robust theory from qualitative data [9, 31]. As explained earlier, grounded theory is an analytical process that makes constant comparisons within the data. The first step typically involves 'open coding' where the analyst compares events, actions, or interactions with others for similarities and differences. Conceptually similar events are grouped into categories and subcategories. In the next step of 'axial coding,' categories are related to subcategories and analysts test these relationships against the data [32]. Selective coding is the next level of analysis, where all categories are unified around a core idea and descriptive detail is added to the categories that need further explication. As we documented a set of preliminary themes, we saw tensions emerging that emphasized resistance to the idea of making sustainability part of mainstream engineering. The parallels with ecofeminist research emerged with the preliminary rounds of analysis, as it should in grounded theory. Therefore the ecofeminist framework did not contribute to the research design but only emerged with the data analysis. Both grounded theory and ecofeminism acknowledge the existence of multiple truths and are open to context-based theories; therefore both approaches are compatible with our research objective and questions.

We have coded our data at three levels, following Corbin and Strauss [9]. Two of us started with a preliminary open coding of the abstract of each article using the sentence as the unit of analysis. This was followed by open coding of the actual article using the paragraph as the unit of analysis. Each code was attributed a 'bin' with corresponding extracts from the text assigned to the bin, based on their relevance to the code. We then followed this step with axial coding, where connections were made with small themes generated across all the articles. Finally, in the third phase of coding, relationships between these codes were generated through selective coding. After the 35th article, we noticed that the smaller themes emerging from the data started repeating themselves to the point that we were not generating newer themes, suggesting we were reaching theoretical saturation. We kept coding until we were no longer adding or modifying any codes, which occurred after coding our 42nd article. To establish that saturation had indeed occurred, we spot-checked abstracts of 40 additional articles in our database of 150 articles and found no new themes in addition to those that had already emerged.

We have presented some numbers associated with the frequencies with which various themes appeared across the body of papers. However, our primary goal in this research is not so much to figure out the exact numbers of occurrences as much as it is to present rich, thick descriptions to describe how sustainability gets marginalized even within the engineering education literature that advocates for sustainability.

4. Results and discussion

4.1 Comprehensive themes

In the axial coding phase [9] we grouped ten themes into sub-groups, made sense of relationships between themes within sub-groups and generated three comprehensive themes that encompassed the smaller themes. These 'meta'-themes represent umbrella categories that we identified inductively based on possible relationships between smaller themes. We also noticed that certain small themes emerged more prominently than others, and so expanded them. Our three comprehensive themes are as follows.

1. Sustainability as a skill set for the future engineer.
2. Sustainability (in)disciplined.
3. Sustainability as value-based engineering.

We will describe each comprehensive theme and its sub-themes (outlined in Table 1), and provide an example or two (in most cases selected from among many) drawn from the literature we were coding that illustrate each idea.

4.1.1 Sustainability as an important skill set for the future engineer

The first comprehensive theme refers to the idea that sustainability could be an important tool in the skill sets of the future engineer. From the ecofeminist

Table 1. Themes and sub-themes, by occurrence

Comprehensive theme	Sub-theme	Occurrences
1. Sustainability as a skill set for the future engineer	a. Super engineer vs. traditional engineer	14
	b. Conventional vs. contemporary engineering practices	18
	c. Employability	3
	d. Engineers as problem solvers, problem definers, and more	9
	e. Role of technology in sustainable engineering	11
2. Sustainability (in)disciplined	a. A discipline, or component of existing disciplines	4
	b. Interdisciplinary or transdisciplinary	15
	c. 'Normalized' vs. 'soft'	7
3. Value-based engineering	a. Sustainability in relation to industry	9
	b. Value	9

perspective, this would involve the ability of a future engineer to correctly estimate, to the best of her/his ability, the broader impact of her/his designs on the environment. Clift [33] provides an example of this theme.

> Post-normal science introduces or reinforces the role of the technical specialist as an agent of social as well as technological change. Such a normative role will be unfamiliar, and probably uncomfortable, to many practising engineers. However it can also be seen as a way of enriching professional practice. If presented right, it could make engineering in general and chemical engineering in particular more attractive to potential new recruits, and thereby help to overcome the problem of declining recruitment to the profession which is apparent in many parts of the world. (p. 4186)

Colleges and universities have an important role to play in the development of engineers' understanding of the broader impact of their work. While classroom learning is one important aspect of learning, Petersen [34] argues that involving students in the development and management of the college campus would give students the opportunity to build those skill sets.

> Today's college graduates confront the first truly worldwide environmental challenge, that of balancing the carbon budget—the stocks and flow of carbon through the biosphere—to ameliorate the negative consequences of global climate change. Colleges and universities have an obligation to ensure that we provide our students with the knowledge and experience necessary to accomplish that challenging task. Many of those essential lessons can take place in classrooms, while an equally educational, parallel curriculum is embodied in the management and development of campus infrastructure, the maintenance of grounds, and the provisioning of food and transportation for our students. (p. A25)

McKay and Raffo [35] gives the readers a better sense of the kind of problems sustainability requires engineers to solve and the kind of skill sets that they may need in the process.

> Most sustainability problems are system problems (for example, transport or food consumption) and almost insoluble. To address sustainability issues, designers need to be able to understand design problems in context, envisage and describe better future systems, and then design products that could be part of a new improved system. This aligns with one of the specialist skills for designers identified through the United Kingdom Design Council's Design Skills Campaign, namely, envisaging future needs. (p. 1106)

The comprehensive theme included five smaller themes summarized in Table 1. We treat each in turn below.

a. *Super engineer versus traditional engineer*. The 'super engineer' in this theme refers to the contemporary engineer who not only performs the traditional engineering task of problem solving but also understands the broader socio/economic/environmental system in which she/he functions. Conlon [17] gives us an example of this through what he terms the 'New Engineer':

> The 'New Engineer' will be a broad based professional who is socially and environmentally responsible. The demand for the 'New Engineer' is reflected in changing approaches to the accreditation of professional engineering programmes. Like professional bodies in other countries, Engineers Ireland (EI), previously known as the Institution of Engineers [of Ireland] (IEI), has changed accreditation criteria to include outcomes focused on ethical standards, responsibilities towards people and the environment, teamwork and communication. Programmes are required to develop an awareness of the social and commercial context of engineers' work and the constraints that arise from that context. (p. 151)

We identified the themes using paper and pencil techniques, and followed this up by tracking occurrences using Excel. This theme occurred in 14 articles out of 42 (see Table 1 for more details on themes and occurrences).

We saw from these papers that 'traditional' engineers have a narrow understanding of their work but value depth while 'modern' engineers have a broader outlook towards how their work fits in with sustainable engineering, as described by Morris et al. [36]:

> The perspective on engineering courses is that engineers have traditionally been less likely to be taught using a broad and integrated approach. They are more likely to be taught in depth, rather than breadth, and in

a linear, step-by-step fashion. There is usually a chance to practice one subject in application through a final-year project, and a hope that they can integrate the remaining subjects once they reach industry. They are also less likely to adopt reflective practices. (p.138)

With a perspective that is broader than the immediate problem, the modern/new age engineer is likely to look at engineering as above and beyond technology to include processes and waste. Engineers also get caught in a dialectic of convention and contemporary. The intersections of convention and contemporary form our next emergent theme.

b. *Conventional versus contemporary engineering practices.* This theme refers to the interplay of traditional and contemporary engineering practices that together help to move various disciplines of engineering in the direction of sustainable engineering practices. Vanasupa et al. [14] provide an example that differentiates between a conventional engineering practice and a contemporary one:

. . . suppose a designer was asked to design a system to protect workers from exposure to toxic vapors in the workplace. By viewing these workers as isolated within a conceptual system boundary, one solution could be to install some kind of vent that removes vapors from the worker's system to 'the surroundings.' However, if this vent moves the vapors to the public and environment at large, it has created a different problem. Once this vent system is implemented it is often the case that the 'solution' to such consequences would be further engineering using the same line of thinking. We might try to deal with the vapors in the public space, rather than addressing the vent system or even the industrial process producing the vapors originally. That process replicates itself outward to a point of collapse wherein the unsustainability becomes immediately apparent in time and space. Essentially we naturally seek to conserve our successful engineered solutions. By using an integrated approach, one might seek to instead redesign the system so that toxins were not used at all. (p. 441)

Contemporary practices therefore require an engineer to be mindful of the consequences of the toxic vapors not only on the immediate population of the workers (fatal short-term consequences) but also on the population who will then breathe the harmful gases over the long term with less visible short-term consequences. In keeping with the earlier themes, much of contemporary engineering also involves being able to communicate this vision and work with the broader public and stakeholders to garner support for this perspective. Clift [33] gives us an example:

System-based tools for environmental management already embody chemical engineering principles, albeit applied to broader systems than those which chemical engineering conventionally covers. Clean technology is an approach to process selection, design and operation which combines conventional chemical engineering with some of these system-based environmental management tools; it represents an interesting new direction in the application of chemical engineering to develop more sustainable processes. Less conventional applications of chemical engineering lie in public sector decisions, using the approach known as post-normal science. These applications require chemical engineers to take on a significantly different role, using their professional expertise to work with people from other disciplines and with the lay public. (p. 4179)

The ability to think above and beyond the immediate problem is sometimes considered out of the purview of conventional engineering practice while contemporary practices include the 'broader' perspective. It is in this interplay of convention and contemporaneousness that we find where sustainability stands in terms of helping engineers make themselves more employable.

c. *Employability:* We have, in an earlier section, highlighted how sustainability brings a breadth to the engineering thought process that has usually otherwise tended towards specialization. Some authors in our dataset explain how the needs of the industry are changing. Engineers who focused on developing specialist skills at the start of their careers now need to have the ability to solve complex, real-world problems outside of that specialization right from the start. This example is an extensive quote from Steiner and Laws [37]:

For a long time industry's demands on the university emphasized the need for specialists in single disciplines who could solve specific problems based on know-how and routines developed in their studies. For complex problems (e.g. strategic questions), firms relied on experienced employees who had already gained general knowledge of the overall company system by working in relevant fields inside the company. Employees began this step-by-step development of competencies by applying routines and proven solutions to solve simple and complicated problems. Employees who were willing and capable, or were forced by their company to enhance their competencies, would gradually become involved with more complicated problems, finally progressing to complex problems.

Whereas the young employees, in particular within the engineering domain, were expected to carry out specialized duties similar to 'plug and play,' when they moved from specialized to more general duties with a high demand on strategic competencies, further competences were required, such as communication, acquisition, etc. The demands on university graduates have changed drastically, especially in fields with high social impact. Graduates are expected to bring the competences needed to solve complex problems with them instead of acquiring them over a long period of practice. This changes the demands on the university which has to react to these changed demands in order to provide graduates with the needed competences for dealing with complex real-world problems. (p. 326)

Yet there are others that see the necessary slant of sustainable engineering towards social responsibility thereby rendering the engineer more 'unemployable,' given the conflicting value systems. Conlon [17] writes:

In this paper, social responsibility will be understood as involving a commitment to a socially just, equitable and sustainable world. I will argue that a focus on employability alone will not equip engineers to be socially responsible because it fails to problematise the current structure of work and society. (pp. 151–152)

This tension between sustainability as enabling employability or preventing engineers from being employable was reflected in three out of 42 articles that we analyzed. We found the idea of sustainability reflecting engineering 'values' in nine of the 42 articles (see Table 1).

d. *Engineers as problem definers, problem solvers and more:* The idea of engineers as 'problem solvers' is prevalent in engineering [8, 38–40]. The idea that engineers also need to be 'problem definers' [41] was also reflected in our data with this theme occurring in nine out of 42 articles (see Table 1). Vanasupa et al. [14] gives an example of a limited problem solving approach:

For example, grocery store patrons are confronted with the choice of paper disposable bags or plastic disposable bags for their purchases (i.e., 'material' cause). However, any benefits of the material choice are made irrelevant by the systemically damaging effect of the design (i.e., 'formal' cause) of a system. The system requires a constant supply of energy, materials and resultant pollutants to manufacture packaging that will be used once and disposed. What is the intent of such a system? It may be something like, 'Serve the economy by creating a disposable bag market,' This purpose does not consider the finite nature of energy and materials from the environment nor the infinite sink required for resultant waste with respect to the product life cycle. (p. 439)

In contrast, in talking of engineers as problem solvers, Allenby et al. [8] emphasizes the high levels of complexities that engineers work with, which require (and value) engineers' quantitative skills:

Engineers are basically problem solvers. Whether working for a private firm, a government agency, or as an independent consultant, an engineer's primary responsibility is to produce a solution that works in the real world, with all the constraints that entails. Such constraints may be competitive, ergonomic, regulatory, economic, and temporal (such as time to market), and are often complicated by implicit and explicit customer preferences.

The constraints are often different for different customer groups. In addition, most engineering activities involve other stakeholders as well, especially where workers (and thus occupational health and safety issues) may be important. Because the public relies on many engineered products, processes, and structures, virtually all engineering occurs in highly regulated environments. Globalization, with its mix of differing cultures, technological infrastructures, and regulatory regimes, adds to the complexity. (p. 20)

Crofton [40] supports Allenby's argument identifying problem solving as one of the key skills that engineers must have. Crofton further states that decision making with a good grasp of global systems should be made one of the key goals of engineering education:

. . . there is general agreement that undergraduate engineering education must provide both specialized and general knowledge and skills; that knowledge/ content areas should include mathematics, natural and physical sciences, engineering sciences and design, management, economics, communication and ethics; and that technical, organizational, managerial, interpersonal, problem solving and planning skills should be included. (p. 399)

. . . Our knowledge of ecosystems and the interdependence of technology and society is rapidly increasing. Engineers will need a good grasp of global systems and ecosystem principles; an understanding of risks and impacts (social as well as environmental) associated with solution options; and a command of tools and technologies needed to guide decision-making and responses to inevitable challenges. Without a long-term vision of the professional engineer which simultaneously addresses the goals, principles and underlying requirements of both sustainability and engineering, it is difficult to enter into a discussion of where engineering education should go from here. (p. 399)

Thus problem definition *in addition to* problem solving requires the engineer to have not only quantitative, technical, economic, and social skills, but also long-term, global systems approaches. Donnelly and Boyle [42] further emphasize that, despite all the training and long-term focus, engineers of today are constrained by existing designs that have been passed on to them:

The traditional role of the engineer has been as the problem solver, and, to a large extent, this is the role that most engineers fulfill today. But, if engineers are to deliver sustainability, then simply being problem solvers is not sufficient. Engineers need to look beyond the problem as it is presented to them. . . . The Catch-22 is that even if engineers are able to effectively frame the problem, they are usually constrained in addressing the broader issues. In a large city, the sustainability of water services on a single site is entirely dependent on the sustainability of existing, centralized systems. The sustainability of centralized systems can only be addressed through regional planning processes, which tend to focus on traditional, not sustainable, infrastructure solutions. (p. 151)

e. *Role of technology in sustainable engineering:* This sub-theme emphasizes the role of technology in helping and also hindering sustainability. Kamp [43] argues that technology is seen as a useful tool that can stimulate sustainable development:

> Is technology hindering sustainable development or can it be used to stimulate sustainable development? It is becoming clearer that technological innovation can be a useful tool for achieving sustainable development. That is, if the technologist is aware of the boundaries that should be considered when working in a sustainable way; and is knowledgeable about how to use the tools that can be used to work in a sustainable way. Therefore, making technology students aware of these boundaries and tools is an important educational task for universities. (p. 928)

In contrast, Lau [5] argues that thinking of sustainability merely in terms of technology (i.e. 'technocratic sustainability') limits the discussion and leaves out non-technical aspects such as cultural and ethical issues:

> Technocratic sustainability is aligned with our modern worldview that technology is the key to progress. Rather than bringing our attention to the political, cultural and ethical issues related to sustainability, technocratic sustainability limits the discussion to science, engineering and business. Considering the sustainability discourse in this way, the typology of environmental sustainability is primarily technocratic, just as is the concept of sustainable development. The global ethic of sustainable development 'is presented as being maximum sustainable consumption of optimally efficient technologies'. (p. 254)

A technocratic focus could mean we limit our gamut of possible changes to using a hybrid sedan rather than a low-mileage SUV, when a deeper discussion on cultural attitudes towards sustainability could open up the possibility of restructuring entire cities, living and working choices so people may walk to work and errands and avoid the need for gasoline-powered choices entirely.

We have discussed the sub-themes and polarities of being a 'super engineer' versus a traditional engineer, the interplay between tradition and modernity, employability, problem solving-problem definition, and technology's role in sustainable engineering. These sub-themes made up the comprehensive theme of sustainability as an important skill set for the future engineer. In the next section, we talk about the comprehensive theme of disciplines and sustainability.

4.1.2 Sustainability (in)disciplined?

This comprehensive theme captures the vibrant debate of the place of sustainability in engineering education and practice and how sustainability challenges existing disciplinary boundaries. It emphasizes the ecofeminist theme of 'interwovenness' as opposed to traditional discipline-based silos. This comprehensive theme included the following three sub-themes outlined in Table 1; we describe and provide examples of each below.

a. *Sustainability as a discipline by itself, or a component of existing disciplines.* Across our dataset, we saw considerable debate and coexisting tensions about where exactly sustainability fits in the disciplinary system. Some scholars felt that sustainability should fit into the disciplinary structure of universities to give it the necessary institutional value to prompt its study, while others felt that sustainability shoehorned into disciplines would also hamstring the interdisciplinary thinking required to understand its chaotic and systems-level aspects. As an example, Ashford [44] discusses the need to rethink disciplinary structures in universities to consider sustainability:

> Scholars and professionals committed to fostering sustainable development have urged a reexamination of the curriculum and restructuring of research in engineering-focused institutions of higher learning. This article will address the following themes and questions: How can multi- and transdisciplinary teaching and research coexist in a meaningful way in today's university structures? Does education relevant to sustainable development require its own protected incubating environment to survive; or will it otherwise be gobbled up and marginalized by attempting to instill it throughout the traditional curriculum? (p. 239)

The argument for sustainability as a discipline is strengthened by the advent of journals such as *Sustainability Science*, which call for research on multiple aspects of sustainability and invites contributions from what Komiyama and Takeuchi [45] call 'people of all walks of life' (p. 2), as well as the development of sustainability-focused departments (such as the School of Sustainability at Arizona State University).

The contrasting perspective is represented by this quote from Mihelcic et al. [46] who call for a new 'metadiscipline' of sustainability science and engineering:

> A case is made for growth of a new metadiscipline of sustainability science and engineering. This new field integrates industrial, social, and environmental processes in a global context. The skills required for this higher-level discipline represent a metadisciplinary endeavor, combining information and insights across multiple disciplines and perspectives with the common goal of achieving a desired balance among economic, environmental, and societal objectives. Skills and capabilities that are required to support the new metadiscipline are summarized. Examples of integrative projects are discussed in the areas of sustainability metrics and integration of industrial, societal, and environmental impacts. It is clear that a focus on green engineering that employs pollution prevention and industrial ecology alone are not sufficient to achieve sustainability, because even systems with efficient material and energy use can overwhelm the carrying capacity of a region or

lead to other socially unacceptable outcomes. To meet the educational and human resource needs required for this new discipline, the technological and environmental awareness of society must be elevated and a sufficient and diverse pool of human talent must be attracted to this discipline. (p. 5314)

We can see in the next section that the contrasting perspective of sustainability and disciplines emphasizes sustainability's interdisciplinarity, or the fact that it can be integrated seamlessly into other disciplines.

b. *Sustainability as an interdisciplinary concept.* This sub-theme emphasizes that sustainability is broad enough to entail participation of multiple disciplines, it should remain an interdisciplinary concept with the disciplinary boundaries being permeable. In the previous section, we saw that Komiyama and Takeuchi [45] called for the discipline of sustainability science. Yet as they explore the content of the discipline, they emphasize its transdiciplinarity:

Precisely because sustainability science includes global, social, and human systems in its purview, and because the problems it addresses involve disparate elements—from science and technology, to politics and economics, to human lifestyles and behavior—this new discipline must necessarily embrace the social and natural sciences. But as the body of academic and scientific research continues to grow, and as the disciplines engaged in this research continue to fragment, it becomes almost impossible for the individual researcher or research group to gain access to and utilize this vast accumulation of data. We need, therefore, to construct a framework within which individual disciplines can provide quantifiable criteria and indicators related to sustainability. By integrating these criteria we can structure our knowledge, our methods, and our grasp of the issues we confront. This is the first step we must take if we are to progress from identifying problems to solving them. (p. 5)

Moore [3] goes a step further in arguing that major issues in the world are interdisciplinary in nature, making a case for doing away with the 'silo mentality' and exposing undergraduates to interdisciplinary thinking right from the start of their college experience:

Despite a long list of warnings from academics, universities continue to be discipline centered and teach undergraduates subjects as if they were arranged in tidy boxes (or so it may appear to undergraduates). (p. 543) Most of the major problems in the world are not disciplinary in nature (i.e. climate change, overconsumption, poverty, global trade issues). Because sustainability issues are interdisciplinary in nature, it is imperative that undergraduates be exposed to the problems and products of interdisciplinary thinking and research. (p. 544)

As these discussions of the boundaries of sustainability take different stances, sustainability itself tends to get sent to the margins of engineering.

c. *Sustainability as 'normalized' versus 'soft.'* Over and over in this literature, we read about how consideration of sustainability was considered a 'soft' skill, which made it considered unnecessary or superfluous to many science and engineering curricula. This is evident in this example from El-Zein et al. [47]:

Another issue in the course design is how to make the course attractive to students who usually view technical subjects as the only essential part of their curricula. The perceived 'qualitative' nature of the course is bound to devalue it in the eyes of applied science students who often equate 'usefulness' with numerically-based design and analysis skills, rather than conceptual rethinking, communications across disciplinary boundaries and complex decision-making where technical knowledge is only one among several other considerations. This obstacle is particularly significant when the relationship of the course learning outcomes to professional practice are articulated in the classroom. While the relevance of the learning outcomes is not in doubt, many students see 'technical design and execution' as the only skill worthy of their curricular time. The problem, in other words, is not only how to change deep-seated mental habits and get students to think outside the 'technical' box. It is also one in which students are asked to rethink what is significant in their curriculum and future careers. (p. 175)

The contrasting theme in the literature insists that sustainability should be considered a normal part of engineering and engineering education and even a prerequisite of engineering design, such as in our earlier work [30]:

[. . .] it is clear that sustainability is, in fact, a prerequisite for *all* good engineering design; it is not a fad concept, but is instead an expression of core values of long-term engineering that recognizes the increasing realization that the long-term and large-scale will be forgotten if not explicitly included in the design process. We have termed this conception 'normalized sustainability,' where we convey to students the viewpoint of sustainability as a normal part of the essence of engineering and a standard part of the design process, and not an added-on, uni-disciplinary, or 'special interest' concern. (p. 367)

This perspective of sustainability as a normal part of engineering is in direct contrast with views on sustainable engineering that marginalize sustainability as 'soft.' For example, some of the key criticisms leveled against sustainability discussed by work in our sample include phrases such as 'not relevant to engineering' (documented by Boyle in [1]), 'hard to scope', 'conceptually abstract', 'too broad' and 'no scientific basis' documented by Leal-Filho [16] and 'new', 'does not fit into disciplines' [3].

This section discussed the debates surrounding the disciplinary aspects of sustainability. We now look at the third comprehensive theme that talks about sustainability as value-based engineering.

4.1.3 Sustainability as value-based engineering

This comprehensive theme emphasizes the ethical realms in which sustainability operates. In this literature, authors argue that mainstream engineering positions itself as objective, quantifiable, and apolitical; they (and we) note how sustainability has a normative and social justice aspect to it that has also contributed to its marginalization from mainstream engineering. In the ecofeminist sense, the ethic of care that sustainability emphasizes brings it closer to nature, which we believe contributes to its labeling as 'soft.' Boyle [1] highlights the lack of acceptance of sustainability as a concept essential to engineering:

> Many engineers, including academics, still do not accept that sustainability has any relation to engineering and some of the most vocal opposition to sustainability comes from engineers who are convinced that technology can solve any problem faced by humanity. Consequently, such academics oppose the inclusion of sustainability within any engineering programme, sometimes quite vocally, to both students and staff. This has a profound effect on the value that students place on incorporating sustainability into their design or even in taking a course on sustainability seriously. (p. 152)

This comprehensive theme includes two subthemes, summarized in Table 1, and described further below.

a. *Sustainability in relation with industry.* We observed in our data the idea that sustainable engineering shares an uneasy relationship with industry and corporations where it is both in opposition to the profit motive and yet also a great tool to build and sustain an ongoing relationship with stakeholders; this latter idea forms a large part of corporate social responsibility initiatives. Engineering educators and others have debated whether training engineers to 'fit in' to the workforce in the end involves teaching engineers to follow problematic organizational agenda [48–50]. Sustainability and its focus on social responsibility might then oppose the status quo in industry where business interests and short-term profit form important decision-making criteria. This quote from Conlon [17] illustrates this point:

> The significance of this for social responsibility is that it raises questions about whose problems engineers are trying to solve and on what basis. In most cases engineers tend to be absorbed in management hierarchies and values and tend to use business considerations as appropriate criteria for engineering decision-making. . . . the discourse of business (and science) has dominated engineering. They argue that while engineers are keenly focused on productivity they do not see the fair distribution of the benefits of economic activity as their concern. (p. 153)

This tension between business and fairness of distribution also impacts decisions on what kinds of technology ('resource intensive' versus 'clean') get used in production and who the targets of production are (the wealthiest or the larger populace in need of safe and affordable means of production). Mihelcic and colleagues [51] argue:

> In order to be sustainable, engineers need to apply appropriate technology versus resource intensive technology that can pollute, create social injustices, and disrupt communities. Engineers and scientists also need to be trained to innovate new ideas and services (which will create employment and exports), so they do not just address the needs of the wealthiest 5% of people in the world, but instead they create and export knowledge and products to the billions of people who are in need of safe and affordable technology. Future technology leaders also need to eco-innovate new services and products embedded in concepts of sustainable development that will create employment and expand markets. (p. 257)

While sustainable engineering, with its long-term social justice focus, does have a tension-filled relationship with the short-term profit-oriented aspects of business, some authors emphasize that industry is also taking steps in sustainable directions. Zimmerman and Vanegas [52] argue:

> The private sector is embracing sustainability as evidenced by the world's largest engineering company, General Electric, launching Ecomagination as a strategic opportunity for the business and the environment, with Fortune 100 companies naming Chief Sustainability Officers, with the Dow Jones and FTSE indexes developing analogous indices for corporate social responsibility and sustainability that have outperformed their traditional counterparts and with the establishment of groups such as the World Business Council for Sustainable development. (p. 242)

This could be viewed as a situation where industry is co-opting sustainability [53] and re-interpreting it to its own ends. However, corporations are important stakeholders not only as future employers of engineers trained in sustainability, but also as places with most of the resources that are needed to make the large-scale changes needed for sustainable production and consumption. Davidson et al. [54] emphasize the multiple stakeholders that engineers need to please with their work. Furthermore sustainable solutions do have high upfront costs while the benefits accrue only over the long term.

> With mounting evidence that an ever-growing population is straining the Earth's resources, why have engineers not made changes in their practices? The answer is clear: there are always pressures to get the job done at the lowest cost and following what the client wants, which usually means using tried and tested methods. It is simply not good business to deviate from accepted methods until changes are required by

regulations or by a changing environment. The next generation of engineers is likely to find that very different pressures are emerging, such as limitations on fossil fuels, restrictions on the availability of land, and use of products that are less harmful to the environment. Furthermore, controversy is likely: there will certainly be opposition to the new paradigm, as the costs will be high and the changes will affect huge numbers of people. But the risks of not supporting the new paradigm will also be high, and some of the most-feared changes may be irreversible. (p. 290)

Donnelly and Boyle [42] discuss another approach to sustainability where assessments emphasize incremental changes as opposed to long term, paradigm shifts. One example could be the increasing use of hybrid cars, an incremental solution aimed at reducing oil consumption, as opposed to redesigning our entire approach to mass and individual transportation that involves elimination of oil dependency. They argue:

However, current sustainability assessments neither measure sustainability nor ensure the survival and continued functioning of human and natural systems and their processes. Current sustainability assessment approaches do not consider medium or long-term features and, therefore, ignore the needs of future generations; they do not consider cumulative impacts across society but tend to provide justification for incremental impact. In addition, these assessments do not challenge existing paradigms of thinking or growth development and cannot provide justification for more sustainable options, particularly where acceptance of such options is currently judged only on short-term economics. (p. 150)

Unfortunately, engineering more sustainable solutions is very difficult within the status quo because alternative paths of development can only be entertained within the context of current social, political, economic, and institutional arrangements. Proposals that require a radical departure from existing paradigms are unlikely to reach implementation, regardless of whether they may be necessary and desirable for sustainability. Within the context of current social, cultural, political, economic, and institutional arrangements, it can be very difficult to generate the incentives for engineers to actually pursue more sustainable ways of doing things. Thus, in the absence of regulations requiring a sustainable outcome, any sustainable solution must compete directly with conventional solutions. (p. 151)

The theme of tracking corporate attitudes with respect to sustainable engineering appeared in nine articles (see Table 1).

b. *Sustainability as a value*. The sustainable engineering education literature emphasizes normative principles such as 'values,' 'roots,' and 'sustenance' that seem far removed from the measurable, quantifiable and objective perspectives of technology [22]. We can see this in this example from Lau [5]:

Sustenance becomes the organizing principle of society's relationship with nature. We are then forced to communally confront normative questions such as: 'What are our values? What are our roots? What sustains us? What do we want to pass on to our grandchildren?' It is not just a matter of examining the ecological means to determined ends; ultimately sustainability requires a political normative judgment on the ends themselves. (p. 254)

And yet, ecofeminist theory might suggest that these ethical and normative aspects of sustainability are what are so important for traditional engineering to incorporate into its regular practice, although simultaneously it is these ethical and normative aspects of sustainability that so clearly separate sustainability from the objectivity of traditional engineering. The difficulty in quantitatively measuring ethics and values as non-objective introduces a 'softness' to sustainable engineering, which ecofeminist theory helps us see as contributing to its marginalization.

Hurtado and Hunte [55] further emphasize the ethics involved in making sustainable decisions that invite engineers to consider the societal consequences of technology, an aspect they have long ignored.

For a long time engineers have been accused of neglecting the social and environmental consequences of their work. The standards for acceptable engineering practice are evolving with improved environmental legislation and increased focus on ethics. As such there must be efforts to bridge the gap between sound technical and economical design and the people and environment that should ultimately benefit from engineering. (p. 266)

In talking about societal consequences, Lowe [56] provides readers with a sense of the value shift required to build truly sustainable solutions, where the implicit understanding is that we share the world with other species and that we take care of it for future generations. This perspective emphasizes the fact that we are not at the center and the only ones affected by our actions, which echoes the idea of interdependence that we have seen in ecofeminism.

But above all else, we need a values shift, perhaps away from *Homo sapiens*, which is gendered and a link back to our past, or *Homo economicus*, the depressing view of the individual as consumer, towards what has been called *Globo sapiens*. Pentti Malaska's term for wise citizens of the planet has been developed by Patricia Kelly (2006), who has unpacked the qualities of *Globo sapiens* and developed the educational principles needed to develop two crucial recognitions: that we share this planet with all other species and that we hold it in trust for all future generations. So we need to see the economy as a means to service human needs rather than end in itself and should be committed to *genuine* globalization rather than the recent fad of simply reducing the constraints on corporations. (p. 251)

Across each of these comprehensive themes, we can see connections to the ecofeminism theoretical framework. The skill set an engineer of the future should have requires a fundamentally different conception of the relationship between engineering work in the human sphere and its situation within the natural. While this helps us understand *why* sustainability is sometimes excluded from engineering, *how* does this help advance sustainability from the position to which it has been relegated? Will perhaps the same strategies employed to improve the gender balance in engineering make the engineering profession more receptive to the importance of sustainability? Specifically, noting that Millennial-generation college students are, according to Collaborative Institutional Research Project (CIRP) data, more service-oriented and politically engaged than college students in at least the past 40 years [57], will marketing engineering as a profession that 'makes a world of difference' [58] attract people to the profession who indeed expect to make such a difference—and thus may expect or even demand inclusion of sustainability as part of engineering?

The interconnectedness that ecofeminism emphasizes also relates to the disciplinary/interdisciplinary debate, which is also relevant to the message of 'engineering makes a world of difference,' as these types of problems require the perspectives and contributions of many disciplines. The framework of ecofeminism helps us note barriers to the integration of sustainability into all engineering disciplines: values excised from the explicit stories of an 'objective' engineering are embodied in conceptualizations of sustainability, so when values are marginalized in traditional engineering disciplines, which simultaneously marginalizes our professional conceptualization of sustainability.

4.2 Polarities

As we developed the ten themes we have just discussed, we realized they can also be thought of as representing 'polarities' [59]. As we suggested through the previous section, included in the same theme are often what are presented as dichotomous concepts found in the literature, or concepts in direct opposition to other similarly themed concepts. As an example, we found some authors strongly supported the idea of sustainability as an interdisciplinary concept not being bound by disciplinary silos, while others emphasized the need for sustainability to be established as a discipline in itself to gain respect, and support in more ways than one from the powers that be at the university level. These concepts are in opposition to each other and yet coexist in the literature. While, in general, we found the various themes emphasized the need for a greater understanding among engineers, engineering students and faculty of the broader social, economic and environmental consequences of their work, the polarities pointed to a certain degree of resistance to the inclusion of sustainability related concepts in mainstream engineering, which resonated with the idea within ecofeminism that environmentally friendlier and labor-intensive tasks get marginalized (and become women's work) while technologically heavy work, that may be more harmful to the environment, is better paid and considered men's work [18, 22].

Polarities require different approaches than problems. The principles of 'polarity management' [59] suggest that when approaching a polarity, it is important to consider the strengths of both ends of the polarity, rather than considering only the strengths of one end, and only the weaknesses of the other. A typical example is the work–rest polarity: while our initial inclination might be to favor rest over work, it is important to note the benefits of both rest and work. Considering the strengths or benefits of both ends can enable us to manage the polarity (rather than choosing one end over another), and work towards meeting the goals that both ends of the polarity represent. Polarity management has recently been used in the strategic planning process for Purdue's College of Engineering [60]; what is the opportunity for engineering educators to engage in a similar strategic process to negotiate the balance between the polarities related to sustainable engineering?

Our use of ecofeminist theory can support the management of these polarities. As we have discussed, ecofeminist theory encourages us to resist the dichotomies that we feel presented with, and particularly value assessments that push us to one end or another. If we instead strive to 'reweave' dualities, as we have said before, what new potentials are we presented with? If we consider the potential of viewing a 'super' engineer and a 'traditional' engineer together, of considering engineers as both problem definers and solvers, as sustainability as both a discipline and an interdiscipline? Perhaps we see poles not as dichotomies representing an 'or' but as extremes we connect with an 'and.' How might we manage the polarity between *adding* sustainability to the engineering curriculum while also *maintaining* the number of courses that students must complete and also *maintaining* the core engineering concepts that are already included in the curriculum? We see possibilities—and need—to achieve both goals through First-Year Engineering courses (see, for example, [30]), capstone design courses, and service-learning courses, but also in other key required courses throughout the curriculum [14].

5. Conclusion

In this paper, we have shown how ecofeminist theory could be used to understand the inferior status that sustainable engineering currently occupies in the disciplinary hierarchy with engineering. Within this theoretical frame, and using grounded theory, we closely analyzed 42 of 150 articles in engineering education to look at the ongoing debates and tensions underlying acceptance of sustainability as part of the engineering process as well as education. Finally we spot-checked abstracts of 40 additional papers our larger database of 150 articles to test for saturation.

Our initial analysis found ideas reflecting the ideas of interdependence of all living beings with the environment and marginalization of environment by the idea of technological progress that we had observed in ecofeminist literature. Three comprehensive themes emerged. Prompted by our adoption of ecofeminst theory to help us interpret our results, we also chose to consider these as polarities that could be managed. The first theme looked at sustainability as a challenging skill set for the future engineer; the second emphasized the disciplinary aspects of sustainability; and the third theme looked at the normative aspect of sustainability as engineering.

Our identification of these themes, and the ecofeminist-based decision to consider them polarities to be managed, can help the engineering education community understand better why conversations about sustainability in engineering education may not be progressing as effectively as they should. Some of these themes seem incommensurable: each perspective's proponents may see a different course of action for teaching novice engineers about this difficult concept of sustainability, in part because they do not even agree with each other on what they consider 'sustainability.' While it seems difficult, amongst everything else an engineer-in-training needs to learn, to add in such a complex topic in a four-year curriculum, globally and collectively we cannot afford *not* to include it. Given this, is it more helpful for us to think *organizationally* of sustainability as a discipline, and/or as an interdiscipline, to begin to train future engineers in sustainability? What do we collectively gain or sacrifice with either choice, and how might we reweave these together differently? By training engineering students to see engineering as an objective discipline, how does this help or hamper efforts to educate them in a more obviously value-laden area of sustainability? Is there a special opportunity to connect with this generation of millennial students in a way that will permanently secure sustainability as part of the engineering culture?

Overall, we found it helpful to use ecofeminism as a framework for thinking how sustainability's marginalization in engineering education could be related to its 'soft' ness, its chaotic and system-level character, as these aspects align it not with the core of engineering but with the marginalized feminine. We believe it is a problem for engineering that characteristics of content considered feminine *are therefore of low value*, reflecting more enduring problems with the gendered nature of our profession. Coming instead to reweave and thereby *value* the marginalized feminine into engineering would go far to center sustainability at the heart of a more responsive, globally-aware, future-oriented, and ultimately successful, engineering professional education.

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