Paper ID #43153

Board 370: Research Initiation in Engineering Formation: Literature Review and Research Plan for an Engineering Specific Empathy Scale

Dr. Emmabeth Parrish Vaughn, Austin Peay State University

Dr. Emmabeth Vaughn is an Assistant Professor in the Physics, Engineering, and Astronomy Department at Austin Peay State University. Before join faculty at Austin Peay, she worked in industry as a Product Development Engineer for a commercial roofing manufacturer. She holds a bachelors degree from the University of Tennessee in Materials Science and Engineering. She earned her PhD from the University of Pennsylvania, where her thesis topic was Nanoparticle Diffusion in Polymer Networks. Her research interests include polymer physics, nanoparticle diffusion, and engineering and physics education.

Lily Skau, Austin Peay State University

Lily Skau is an undergraduate student at Austin Peay State University pursuing a bachelor's degree in Engineering Physics and a minor in Mathematics and Sociology. She plans to graduate with her degree and minors in May of 2026 and enter the industry as a Mechanical Engineer.

Dr. Bobette Dawn Bouton, Austin Peay State University

Dr. Bobette Bouton is an associate professor at Austin Peay State University. Her current area of research is socio-emotional development in the domain of empathy. She is a Deweyan Pragmatist who focuses on student-centered teaching and reflection. She also is working toward making higher education a more socially just and safe space for all and uses writing, speaking, and research to address each of these important aspects of her academic career.

Research Initiation in Engineering Formation: Literature Review and Research Plan for an Engineering Specific Empathy Scale

Abstract

Engineers are societal caregivers, solving problems for the betterment of society. However, both practitioners and students of engineering struggle to make concrete connections between empathy and their role as engineers. While general empathy scales exist, these scales do not describe empathy in specific engineering scenarios and other helping professions have unique empathy scales. To address both the empathetic nature of the engineering discipline and the lack of discipline specific empathy understanding, our research team has set out to create an engineering empathy scale (EES) funded by the National Science Foundation. Our research is guided by two research questions: How is empathy conceptually perceived, experienced, and shown in engineering specific situations? and Can engineering specific situations be used to measure empathy in engineering students, faculty, and practitioners? In this article, we present a systematic literature review of empathy in engineering and engineering education. Based on our selection criteria, we found 48 peer reviewed articles. Three themes of the articles emerged focusing on empathy in engineering: teaching and learning, design, and the role of empathy in engineering. We analyzed the articles to determine what areas of connection to the constructs of empathy and the current model of empathy in engineering are supported and which need more research to support. Lastly, we present our research plan to create and validate the EES, which will be aided by this literature review.

Introduction

Engineers are problem solvers. This statement is likely the first heard, and most commonly reinforced, expression communicated to future engineers during collegiate engineering formation. The answer to the follow-up question, why do engineers solve problems? is not as frequently communicated. Engineers solve problems for the benefit of society. Evidence for this role is seen within the National Society of Professional Engineer's code of ethics cannons and rules of practice, the first of which is "Engineers shall hold paramount the safety, health, and welfare of the public [1]." While not every engineer will be providing individualized problem solutions, i.e. care, the discipline of engineering is intended to provide solutions and care to society. Engineers are societal caregivers.

The problems engineers are called on to solve, are complex, not just from an intellectually rigorous perspective, but also from the myriad of societal, ethical, and human elements that contribute to the problem, and must be considered in the solution. Thus, to act as a societal caregiver is immensely complicated. As globalization increases, the practice of engineering will require increasing social competencies to balance technical correctness with interpersonal, cultural, and environmental sensitivity. Empathy, an ability "to perceive the internal frame of reference of another with accuracy" [2], allows an engineer to put themselves in the "shoes" of the people who will be using and interacting with the products and services they create. To this end, empathy is an essential skill needed to understand complex engineering problems and provide solutions that meet the needs of society.

The discipline of engineering has lagged behind other helping disciplines' who have increased their awareness of the importance of empathy in both the education and the practice of that discipline. In the last ten years, however, engineers, and those outside of engineering on behalf of engineers, have begun to see the need for a discipline specific understanding of empathy. To this end, research teams have focused on ascertaining the current beliefs and perceptions regarding empathy within the discipline of engineering [3], [4], [5], [6], [7].These researchers have found that within engineering practice empathy is frequently seen as a tool to be used to improve one's professional abilities or achieve personal goals [8]. Additionally, many practicing engineers consider their work to be intrinsically empathetic in its service to society, supporting the description of engineers as societal caregivers [6], [8].

In seemingly blatant contradiction, while researchers have identified the belief among engineers that empathy is essential to the practice of engineering, researchers have also identified a belief that empathy is not core to the formation of an engineer [5]. One quantitative study on the views of empathy in engineering practice found that the engineers surveyed agreed more with the idea that empathy and care are important in engineering than agreed that empathy and care existed within engineering work and practice [4]. How can a characteristic that is important, or even intrinsic, to the discipline not be displayed or perceived to exist in practice? Researchers have asserted that it is due to the "culture of disengagement" surrounding empathy in engineering [9]. Three pillars of ideology prevalent within engineering create this culture: depoliticization- the separation of "engineering work" from social and political constructs, the technical/social dualism- a devaluation of "social" competences in favor of "technical" competencies, and meritocracy- a belief that hard work and talent reward all equally [9]. Combined, these discipline ideologies create an estrangement between an engineer's work and contextualization of that work, a chasm between engineer and end user.

In an article addressing the current perceptions of the role of empathy in engineering education and practice, the authors paint a bleak view, emphasizing the devaluing of empathy that occurs within engineering education and in engineering educators [8]. Despite the call for preparation of a more socially aware and capable engineer, engineering educators are hesitant to include empathy, and other social competencies, as necessary in engineering training [8]. Indeed, a dominant perception within engineering education is that empathy training should be left to others, potentially due to lack of empathy training engineering educators themselves received during their own formation. This perception, however, is at odds with ABET student learning outcomes, which highlight competencies requiring empathy, such as "ability to… produce solutions… with consideration of public… welfare, as well as global, cultural, social, environmental... factors" and "ability to recognize ethical and professional responsibilities… in global, economic, environmental, and societal contexts" [10]. These student learning outcomes highlight that the technical solutions determined by engineers cannot be separated from their societal context.

This "culture of disengagement" and devaluing of empathy within the engineering discipline has resulted in negative consequences to engineering students and does not prepare them for the roles they will be taking on in their careers as engineers, as seen in studies probing formation of empathy during collegiate engineering training. One study found that engineering students, while aware of empathy definitions and implementation generally, were not aware of, or experienced with, the role of empathy within the engineering discipline [3]. Indeed, in a survey of empathy perceptions of over 1,000 practicing engineers, respondents gave lowest marks to the statement "I learned to be more empathetic and caring during my college years" [4]. These findings are convicting. Engineering educators must not push training on the empathetic practice of engineering to other, less technically driven disciplines. This deficit of training in engineering specific empathy is ultimately a problem in engineering formation that requires a combined effort from engineering educators and social scientists to address.

As interventions are developed to increase empathy and empathy awareness in engineering education and practice [11], [12] methods for assessment must be developed to understand the impact of these interventions. To be able to assess and equip a more empathetic engineer, empathetic capabilities specific to engineering must be measurable. Our research team aims to develop an Engineering Empathy Scale (EES). The EES will use Likert-scale ranking of questions from engineering specific scenarios based on the constructs of empathy and the model of empathy in engineering (MEE) as a skill, orientation, and way of being to assess present empathetic capability of pre-career engineers, engineering educators, and practicing engineers [13]. This scale will help to address the gap in engineering students' awareness of the role of empathy in engineering, through the use of specific scenarios regarding empathetic displays in engineering. Additionally, this work will help address the "culture of disengagement" through creation of a tool in the hands of engineering educators to assess interventions they develop to increase empathy awareness and skill in their engineering students. Ultimately, the research team's goal is that the EES can serve as a self-reflection tool for engineers at any stage to grow in their empathetic capability, so that they can better holistically serve society.

While general empathy scales exist [14], helping professions, such as physicians [15], social workers [16], and teachers [17], have developed discipline specific empathy scales that allow for pre-career assessment and practitioner reflection. Empathy, like other discipline norms, has unique characteristics and roles within a specific discipline. For example, a classroom teacher may empathize with their many students by considering each students' strengths and varying assignments to meet student needs. A therapist's empathy, however, looks very different from that of a classroom teacher; a therapist's empathy allows them to act as a mirror to the client, helping the client see their own feelings and meanings more clearly. An engineer may at times need to empathize with a single user, as may be the case in prostatic development, or an entire community group and the environment, as may be the case in development of a new hydroelectric dam facility. Due to the unique nature of empathy within the discipline of engineering, empathetic experiences and scenarios pertaining specifically to engineering should be used to create a tool for measuring the empathetic abilities of pre-career engineers, engineering educators, and practicing engineers.

Empathy was first rigorously conceptualized and studied within the field of therapy by Carl Rogers, who defined empathy as the ability "to perceive the internal frame of reference of another with accuracy, and with the emotional components and meanings which pertain thereto, as if one were the other person, but without ever losing the ‘as if’ condition” [2]. A more general definition comes from Lam, et. al., who defined empathy as “an individual’s capacity to understand the behavior of others, to experience their feelings, and to express that understanding to them” [14]. Within this three-part definition the theoretical constructs of empathy, the cognitive, affective, and behavioral shown in the top half of Figure 1, emerge. The cognitive construct relates to the mental process of empathy; the affective relates to the emotional process of empathy; the behavioral relates to the physical process of empathy. Recently, through transdisciplinary dialogs between engineering and social work educators, an empathy model specific to engineering was created [13]. This model, displayed in the lower half of Figure 1, proposes that empathy in engineering is a learnable skill, an orientation of practice, and an aspect of professional being. Elements of each construct of empathy are integrated into each of the three dimensions of the model for empathy in engineering (MEE).

Within the dimension of empathy as a learnable engineering skill, there are five comprising components: affective sharing, self and other awareness, perspective taking, emotion regulation, and mode switching. Affective sharing relates to the cognitive process by which one shares the emotions of another; self and other awareness moves one from the cognitive process to the affective by experiencing another’s emotions; perspective taking relates to the behavior of adopting another’s point of view. The component of emotion regulation, has aspects of each of the three empathy constructs: an awareness of one’s own emotional state, the experience of that empathetic emotional state, and an expression of that emotional state when interacting with others. All three empathy constructs are also imbedded within the component of mode switching, which refers to awareness of and ability to transfer between “empathic and analytic cognitive mechanisms”[13].

The dimension of empathy in engineering as an orientation of practice has four components, shown in the middle panel of Figure 1. Each of the components within the practice orientation dimension of the engineering empathy model have the capacity to span each of the general constructs of empathy. For example, within the component of epistemological openness, one may simply cognitively recognize that stakeholder’s experiences and knowledge can serve as an information source when developing a solution, or one may actively seek and use this information. Within the dimension of micro to macro focus, one may understand the “global, economic, environmental, and societal context” [13] of an engineering work, or one may integrate this understanding throughout their work. Similar lines of thinking may be applied to reflective values awareness and values pluralism components, which relate to the multitude of, and at times competing, goals of engineering work.

The professional way of being dimension of engineering empathy provides the “contextualizing framework of broader value commitments” present in the discipline of engineering [13]. Three specific values are called out within the engineering empathy model: service to society, the dignity and worth of all stakeholders, and engineers as whole professionals [13]. Again, aspects relating to each of the fundamental constructs of empathy can be connected to each of these values. It is from these discipline values that the description of engineers as societal caregivers springs. It is the disconnect between these values and the education of engineers which has led, in part, to the need for this and other research works regarding empathy within engineering.

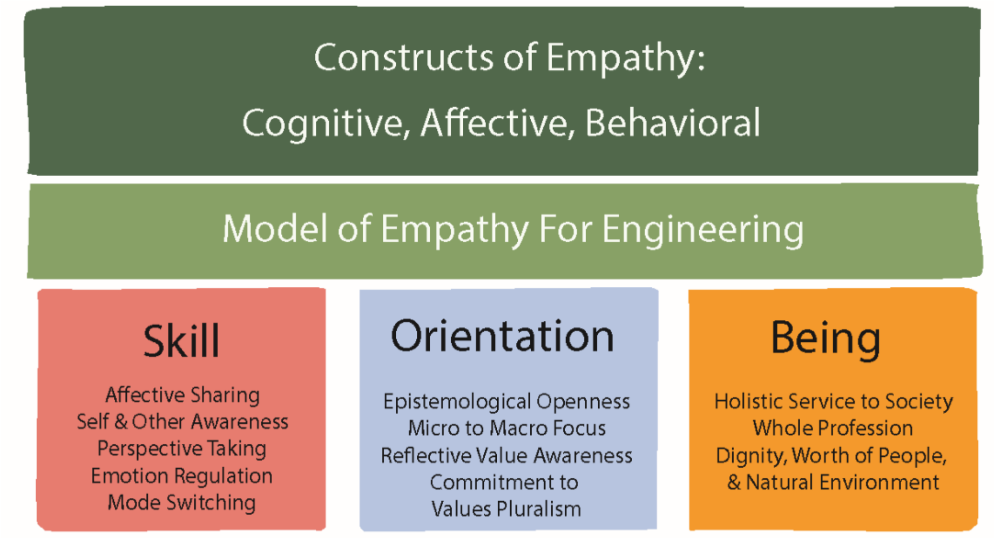

Figure 1: Diagram of the constructs of empathy and a model for empathy *[13]* in engineering.

In this paper, we present a systematic literature review of engineering empathy. Our primary research question was how is empathy represented and studied within engineering and engineering education literature? While some of the articles included in this review contain their own literature reviews on empathy in engineering, here, we go further than previous literature by considering the secondary questions: how does the current literature on empathy in engineering education and practice support the MEE [13] and what empathy constructs and model dimensions need to be further explored? This systematic literature review will ultimately provide context for our NSF funded EES creation, the research plan for which we describe in the future work section.

Method

Positionality

As in all research, it is helpful to understand our positionality and, therefore, the lens through which we analyze the literature. The first author is a white, female U.S.- born engineer with experience in product development and expertise in the field of materials science and engineering. She is a developing engineering education and formation researcher. Second author is a white, female U.S.- born undergraduate engineering student. The third author is a white, female U.S.-born scholar with expertise in empathy research and scale design with a very limited knowledge of engineering training and education.

Discovery, Inclusion, and Selection

To gather potential articles for this review, we utilized our university library's Primo discovery service. This service gathered articles from all of the 322 database subscriptions our library has, notably IEEE Xplore Digital Library, Applied Science & Technology Full Text, Science Direct College Edition Journal Collections, Education Full Text, ERIC, and JSTOR. We searched for article with subjects containing “empathy” and “engineer*”. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) for this article is shown in Figure 2. Many articles in the initial search were identified as unrelated to the current study (n = 522). For this review article, we chose to exclude articles related to application development, software design, virtual reality development, and AI development, of which our initial search contained 49. We are currently working with a computer science faculty member to explore empathy more fully within a technology and computer science reference frame for inclusion in a future publication. Further deselection of 47 articles resulted from reviewing the full text of articles to insure their peer-reviewed nature and relation to both engineering and empathy. After discussion as a research team, 8 more articles were removed as having very limited connections to both engineering and empathy, result in 48 articles included in analysis.

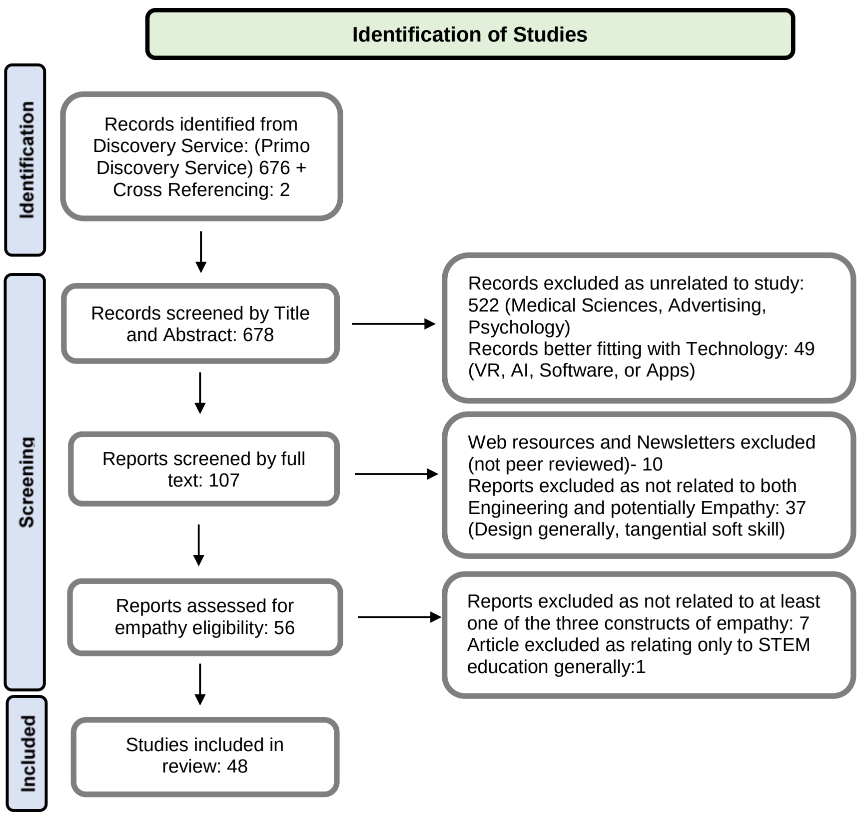

Figure 2: PRISMA showing the identification, screening, and selection process for this systematic review.

Analysis

After reading the 48 articles, our research team identified three emerging themes: Empathy in Teaching and Learning, the Role of Empathy in Engineering, and Empathy in Engineering Design. When determining the category for each article, Dr. Vaughn first made selections for articles, then Dr. Bouton reviewed her selections. For any articles that could be placed in multiple categorizes, Drs. Bouton and Vaughn discussed to achieve agreement about the selected theme. Dr. Vaughn then separated articles into categories within those themes and performed the initial coding for connections to the MEE, while Dr. Bouton coded the articles for their connection to the constructs of empathy. These coding results were then reviewed by the entire research team.

Limitations

We acknowledge that while we sought to perform a systematic review, relevant studies may still be missing from our synthesis. We highlight three potential gaps in our process where relevant studies may have been missed: articles published after July 2023, as this is when we began the synthesis process; articles in journals to which our library does not subscribe; and articles that discuss empathy by means of complementary words.

Results and Discussion:

In reviewing the 48 articles, our research team identified three emerging themes. For the theme of the Role of Empathy in Engineering, articles were grouped as to whether the article addressed defining the role of empathy in engineering, the role of empathy as it relates to gender in engineering, or the role of empathy in engineering formation. Within the Empathy in Teaching and Learning Engineering theme, articles were separated into categorizes based on the level of education the article addressed, namely K-12, undergraduate, or graduate engineering education. Articles related to Empathy in Engineering Design were separated into two categories, those related to product development and those related to user need and experiences. In the following sub-sections, each article will be briefly discussed in the corresponding theme section, highlighting areas of fit with the constructs of empathy and with the MEE.

Role

Many of the articles related to the Role of Empathy in Engineering provided the context for discussing engineering empathy in the introduction, making it the logical starting place for reviewing connections to the MEE and constructs of empathy. As empathy in engineering is a newer field of research, growing over the past ten years, establishing the context for empathy within the discipline is a necessary step for furthering research. Within the theme of the Role of Empathy in Engineering, three sub-categories were identified: Defining the Role of Empathy in Engineering, the Role of Empathy in Engineering Formation, and the Role of Empathy in the Gendered Experience of Engineering. The titles, category, empathy constructs, and connections to the MEE for the 17 articles related to the Role of Empathy in Engineering are shown in Table 1. The author indicated subjects of the 17 articles within this theme are shown in Figure *3*, where the size of the words correlates to the number of times that word or phrase appeared in the keyword or subjects of these articles. As expected, many articles specified empathy, engineering, and engineers as subjects. Additionally, the three categories we identified connect to prominent words. The category of Defining the Role of Empathy in Engineering connects to the prominent words of literature reviews and social responsibility. Engineering education and students align with the Role of Empathy in Engineering Formation. Women aligns with the Gendered Experience of Engineering category. The word cloud of Figure 3 was helpful in supporting the research teams' choices of categories, and also highlights the wide range of topics and disciplines interconnected with the discussion of empathy in engineering, such as social work, philosophy, ethics, care, design, communication, and education.

Table 1: Title, category, empathy constructs, and MEE connections for the 17 articles related to the Role of Empathy in Engineering.

Title	Category	Empathy Construct	Connection to the Model of Empathy in Engineering
A Model of Empathy in Engineering as a Core Skill, Practice Orientation, and Professional Way of Being [13]	Defining	cognitive, affective, behavioral	This is the model.
Empathy and care within engineering: qualitative perspectives from engineering faculty and practicing engineers [5]	Defining	cognitive, affective	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness Orientation-Epistemological Openness, Micro to Macro Focus Being- all
Empathy and Caring as Conceptualized Inside and Outside of Engineering: Extensive Literature Review and Faculty Focus Group Analyses [18]	Defining	cognitive, affective	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness Orientation-Epistemological Openness, Micro to Macro Focus Being- all
Insights from industry: a quantitative analysis of engineers' perceptions of empathy and care within their practice [4]	Defining	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness Orientation-Epistemological Openness Being- Holistic Service to Society
Practicing Engineers' Perceptions of Empathy and Care: Derived Exploratory Factor Structure from a 37-Item Survey [19]	Defining	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness Orientation-Epistemological Openness Being- Holistic Service to Society
Pragmatism and Care in Engineering Ethics [20]	Defining	cognitive, affective	Orientation-all Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
Role of Empathy in Engineering Education and Practice in North America [8]	Defining	cognitive, affective, behavioral	Skill- Perspective Taking Orientation- Reflective Value Awareness Being- all
Designing for others: the roles of narrative and empathy in supporting girls' engineering engagement [12]	Females	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness
Effects of Engineering Students' Soft Skills and Empathy on Their Attitudes toward Curricula Integration [21]	Females	cognitive, affective	Skill- Perspective Taking, Affective Sharing Being- Holistic Service to Society
Empathy and Gender Inequity in Engineering Disciplines [22]	Females	cognitive, affective, behavioral	Orientation-Epistemological Openness, Reflective Value Awareness
The Role of Empathy in Choosing Majors [23]	Females	cognitive, affective, behavioral	no clear connection
Design thinkers can save the world: How understanding their interests, goals, and motivation can inform engineering educators [24]	Formation	unclear	Skill- Perspective Taking Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
Empathic Design in Engineering Education and Practice: An Approach for Achieving Inclusive and Effective Community Resilience [25]	Formation	cognitive, affective, behavioral	Orientation-all Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
Empathy and Engineering formation [6]	Formation	cognitive, affective, behavioral	All Elements
Exploring the Role of Empathy in Engineering Communication through a Transdisciplinary Dialogue [7]	Formation	cognitive, affective, behavioral	All Elements
From 'Empathic Design' to 'Empathic Engineering': Toward a Genealogy of Empathy in Engineering Education [26]	Formation	cognitive, affective, behavioral	Being-all
In Their Shoes: Student Perspectives on the Connection between Empathy and Engineering [3]	Formation	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness Orientation- Reflective Value Awareness Being- Holistic Service to Society

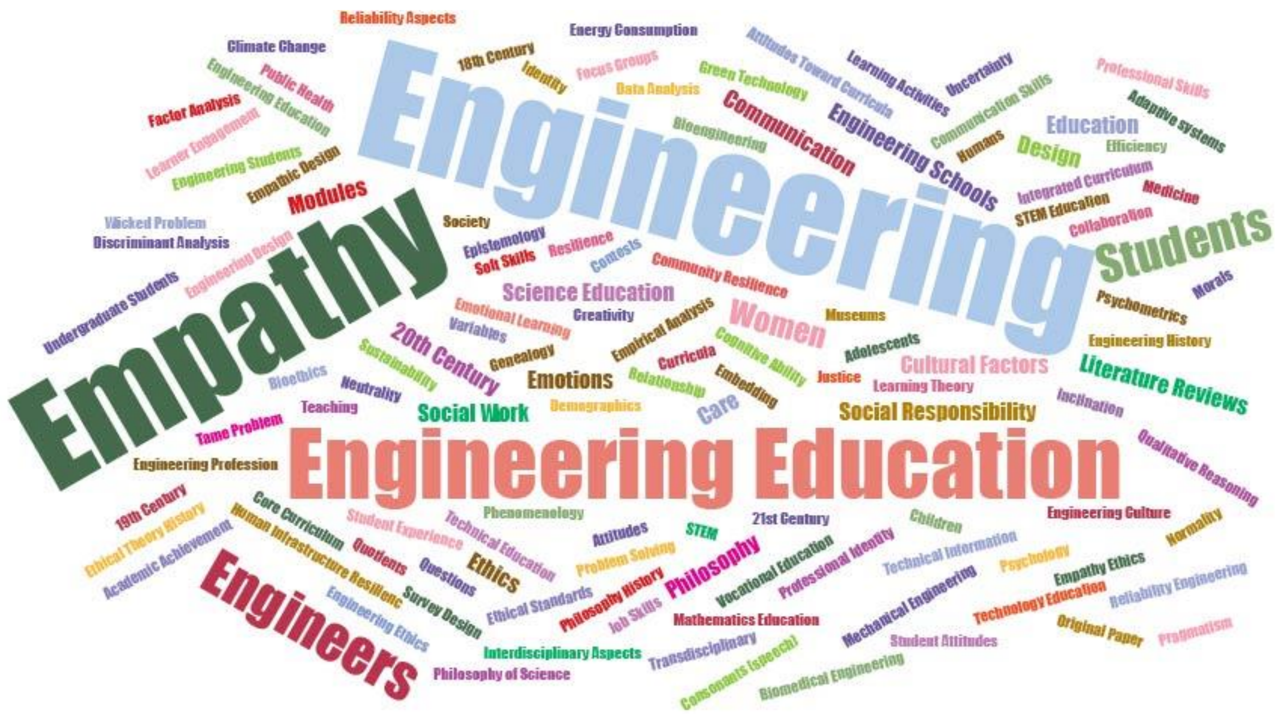

Figure 3: Author indicated subjects for the 17 articles within the Role theme. Size gives an indication of subject occurrence.

Defining

Seven articles addressed defining the role of empathy in engineering [4], [5], [8], [13], [18], [19], [20], including the article which presented the MEE which was discussed in the introduction [13]. Four articles in this section have a common author, Hess [4], [5], [18], [19], who authored 8 articles cited in this review. In two of these articles related to defining the role of empathy in engineering, Hess and coworkers surveyed practicing engineers regarding empathy and care [4], [19]. From quantitative analysis of the survey responses, Hess and coworkers found that approximately one third of surveyed engineers answered neutral or negative when asked if empathy and care were present within their professional practice. The results also, however, indicated that the surveyed engineers perceived that empathy and care were important in both relational and technical aspects of engineering, highlighting the disconnect between perceived and enacted values in engineering practice. The other two articles by Hess and coworkers qualitatively analyzed focus groups of engineering and non-engineering educators to determine perceptions of empathy and care in engineering. The authors found that non-engineering educators perceived engineers as not embodying empathy and care and that many engineering educators did not support empathy and care within the engineering curriculum other than in teamwork [5], [18]. The authors assert, however, that an engineer who lacked empathetic capability, who ignored user needs, was a terrible teammate, and could not incorporate stakeholders values in designs, would not be a very successful engineer, highlighting disconnect between was is valued in engineering education and what is valued in engineering practice [18]. Insights from the articles by Hess provide an example of how empathy is a skill, orientation, and way of professionally being as the MEE asserts, despite the noted disconnect between what engineers want to be, or think they should be, and reality.

The remaining two articles in this category have connections to many of the MEE dimensions of empathy as a skill, orientation, and way of being in engineering as well. Specifically addressing the role of empathy in engineering in north America, Wilson and Mukhopadhyaya highlight how the complex, ill-defined, and value-conflicting problems engineers encountered in practice necessitate socio-technical competencies, such as empathy. Through a discussion of the themes found in literature related to conceptualizations of empathy in engineering, the authors' findings connect to the MEE skill element of perspective taking, the orientation of reflective value awareness, and the way of being that holistically serves society. Notably, the authors' findings highlight that the affective construct of empathy is devalued in dominate engineering culture. While the article by Nair and Bulleit [20] focuses on engineering ethics, the authors express that empathy is "feeling what another person feels"[20], which connects to the affective construct of empathy. The authors pair empathy with care, asserting that these elements should become part of engineering ethics as practiced. While the authors' definition of empathy only addresses the affective construct, throughout the article, the authors express ideas that support the orientation and being dimensions of the MEE. Notably, the authors espouse considering competing values and ideals in an engineering context (Commitment to Values Pluralism) and assert that engineers must consider human dignity when considering technological advancements (Dignity, Worth of People, & Natural Environment).

Formation

The Role of Empathy in Engineering Formation category is closely related to the Empathy in Engineering Teaching and Learning Undergraduates category; the authors distinguished these areas by asking if the goal of the article was to describe a particular course design; curricular or extracurricular activities; pedagogical method, or contextualize the role of empathy in engineering formation more broadly. Two of the articles in this section are by the authors of the MEE, Walther and Miller [6], [7], who authored four articles cited in this review [13], [27]. In these articles, the authors discuss the foundational principles from social work regarding empathy, which ultimately scaffolded the MEE creation, in the context of engineering formation. In one article, the authors qualitatively analyzed student reflections following activities designed to train in empathy, finding that students reflected on the relationship between becoming an engineer and others, the act of learning, and the content of learning. The authors suggest two ways engineering formation may be enhanced through empathic training: first by making "key aspects of students' identity formation visible as well as experientially and pedagogically accessible [6]" and second by using the ways that empathic skills and orientations interplay with engineering identity. Another article in the theme specifically addresses student stakeholders' beliefs regarding the role of empathy in engineering formation [3]. The authors found that while these engineering students largely believed that there was "a limited role for empathy in their engineering work"[3], they believed that empathy was potentially useful in engineering teams, problem contextualization, human-centered design, and individual motivations for pursuing the engineering profession. From the student responses, the authors make connections to all three constructs of empathy. Several of the MEE elements can also be connected to their findings such as the skill of perspective taking in problem contextualization and the way of being that holistically serves society in motivations for pursing the engineering profession.

The remaining three articles sought to articulate how the empathetic principles of design could shape or be re-shaped to enhance engineering education[24], [25], [26]. In the article by Afroogh *et. al.*[25], the authors present the need for more empathic engineers to design and achieve effective community resilience in the face of increasing natural hazards. They suggested that engineering formation must include "situated learning, transformative learning, design-based learning, and clinical engineering along with subjective, systems, and critical analysis [25]" training to develop empathic engineering. Some examples of these learning experiences and necessary analysis methods can be seen in the Teaching and Learning theme articles, for example the clinical engineering that Allen and Chen discuss [28]. The thesis by Blizzard sought to inform engineering education through examining design thinkers, of which they believed empathy would be a characteristic. Empathy, however, did not present as a construct of design thinkers, instead feedback seeking did, resulting in limited actionable translations to this review. In the article by Tang [26], the author argues that a reframing is needed from discussing and teaching "empathetic design" to "empathic engineering", as the former encourages "a narrowly-defined, instrumentalist, and product-oriented conception of empathy[26]". Tang provides two alternative ideas of empathic engineering: a commitment to communication in the face of differences, which connects to the MEE orientation of Epistemological Openness, Reflective Value Awareness, and Commitment to Values Pluralism, and holding "empathy as a professional excellence for engineers [26]", which relates to the MEE dimension of being.

Gendered

There were four articles related to the Role of Empathy in the Gendered Experience of Engineering. Building off previous research findings that empathy is a key factor when choosing a profession, Jacobs *et. al.*[22], propose that a lack of observable empathy within the engineering discipline could be a cause for the underrepresentation of women in engineering fields. In a follow-up article by the same authors [23], the role of empathy in women choosing a major, with an emphasis on engineering majors, is studied through mixed methods. The authors present four key results: that women are more empathetic than men, that students in engineering majors and other STEM majors are generally less empathetic than students in non-STEM majors, that the engineering disciplines are often perceived as less empathetic than other majors, and that empathy is negatively correlated with choosing engineering as a major. While these findings are disheartening, considering the skill dimension of the MEE, empathy can be learned and developed to shift these perceptions and increase representation of women in engineering. Hwang probed gender differences in soft skills and empathy in Korean engineering students [21]. Using a general empathy scale that probed only cognitive and affective empathy, they found that female engineering students scored higher on empathy markers than male engineering students. "As the engineering profession saves and/or betters peoples' lives and society as a whole, [engineers are] self-evidently required to understand the perspective and needs of those being served [21]", making the empathy disparities observed in the previous studies inside and outside of engineering concerning.

While the previous articles in this section related to empathy and gender at the collegiate level, the last article in this section relates to the role of empathy and gender in early, informal engineering interest development [12]. Described in the article is an observational study conducted to determine if and how narrative design elements in engineering activities can foster empathetic behavior and increase engagement in young girls. These girls were tasked with creating a series of inventions as museum activities with the intention of evoking empathy, and different engineering and empathy markers were observed. It was found that participants who demonstrated more empathetic behavior also demonstrated higher engineering activity markers, supporting the idea that incorporating narrative design elements, which elicit or enable empathy, can increase engineering engagement of young girls. While perceived or real lack of empathy in engineering is unlikely to be the sole reason for the underrepresentation of women within the disciple, embedding empathy in the teaching, practice, and culture of engineering must be part of a multifaceted effort if gender equity is to be achieved in the engineering discipline.

Teaching and Learning

The largest theme we identified within the engineering empathy literature was Empathy in Engineering Teaching and Learning. Within this theme, we found articles related to all levels of education, *i.e*. K-12, undergraduate, graduate, except for continuing education. The largest theme and category of articles (n = 15) included in this literature review was empathy in engineering teaching and learning at the undergraduate level. In the following paragraphs we will consider first articles related to specific years within the undergraduate engineering curriculum and those related to undergraduate education generally, move to the four articles related to graduate engineering education, then discuss the six articles related to empathy in K-12 engineering education.

Undergraduate

The titles, empathy constructs, and connection to the MEE for the 15 articles reviewed in the Undergraduate theme of Empathy in Engineering Teaching and Learning are displayed in Table 2. Additionally, the author indicated subjects for these articles are displayed in Figure 4. While expected keywords of empathy, engineering education, and universities are largest, some of the lesser repeated keywords will be used to group the discussion of the 15 articles in this category. Specifically, multiple articles in this section relate to introducing empathy within the teaching context of engineering design, engineering ethics, biomedical engineering, and service learning. Words and phrase related to engineering design appear repeatedly in the word cloud such as engineering design, design engineering, design, green design, and empathetic design, highlighting the importance of empathy in the core engineering process of design. Other repeated keywords that show the wide-reaching context for empathy in engineering teaching and learning are innovation, problem-solving, and training.

Table 2: Title, category, empathy constructs, and MEE elements for the 15 articles related to the Empathy in Undergraduate Teaching and Learning Engineering.

Title	Empathy Construct	Connection to the Model of Empathy in Engineering
A Pilot Study of the Development of Empathy within a Service-learning Trip from a Qualitative Perspective [29]	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Emotion Regulation
Design fixation in STEM teacher education [30]	affective, behavioral	none
Designing a Multi-Cycle Approach to Empathetic Electrical Engineering Courses [31]	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Mode Switching Orientation-Reflective Value Awareness Being- Whole Profession
Empathic approaches in engineering capstone design projects: student beliefs and reported behavior [32]	cognitive, behavioral	Skill- Perspective Taking, Mode Switching Orientation-Epistemological Openness, Reflective Value Awareness, Commitment to Values Pluralism
Empathy and ethical becoming in biomedical engineering education: a mixed methods study of an animal tissue harvesting laboratory [33]	cognitive, affective	Orientation-Epistemological Openness, Reflective Value Awareness, Commitment to Values Pluralism Being- Dignity, Worth of People, & Natural Environment
Empathy, Persuasiveness and Knowledge promote innovative engineering and entrepreneurial skills [34]	behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Mode Switching Orientation-Reflective Value Awareness Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
Feeling the heat: investigating the influence of novice designers' trait empathy, and their beliefs, attitudes, and intentions towards sustainability on their identification of problem requirements [35]	cognitive, behavioral	Skill- Perspective Taking, Mode Switching Orientation-all Being- Dignity, Worth of People, & Natural Environment
Fostering Empathy in an Undergraduate Mechanical Engineering Course [27]	cognitive, affective, behavioral	Skill- all elements Orientation- all elements Being- all elements
How Role-Playing Builds Empathy and Concern for Social Justice [36]	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Mode Switching Orientation-all Being- all
Inner engineering: Evaluating the utility of mindfulness training to cultivate intrapersonal and interpersonal competencies among first-year engineering students [37]	unclear	Skill- Emotion Regulation Being- Whole Profession
Patient Centered Design in Undergraduate Biomedical Engineering [28]	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Mode Switching Orientation-Epistemological Openness, Micro to Macro Focus Being- Dignity, Worth of People, & Natural Environment
Student ethical reasoning confidence pre/post an innovative makerspace course: A survey of ethical reasoning [38]	cognitive	Skill- Perspective Taking Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
The Importance of Incorporating Designer Empathy in Senior Capstone Design Courses [39]	cognitive, affective, behavioral	Skill- Perspective Taking Orientation-Epistemological Openness, Micro to Macro Focus Being-Dignity, Worth of People, & Natural Environment
The manifestation of empathy within design: findings from a service-learning course [40]	cognitive, behavioral	Skill- Perspective Taking, Mode Switching Orientation-Epistemological Openness, Reflective Value Awareness Being- Holistic Service to Society
The Role of Empathy in Supporting Teaching Moves of Engineering Design Peer Educators [41]	cognitive, affective, behavioral	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness, Mode Switching Being- Whole Profession

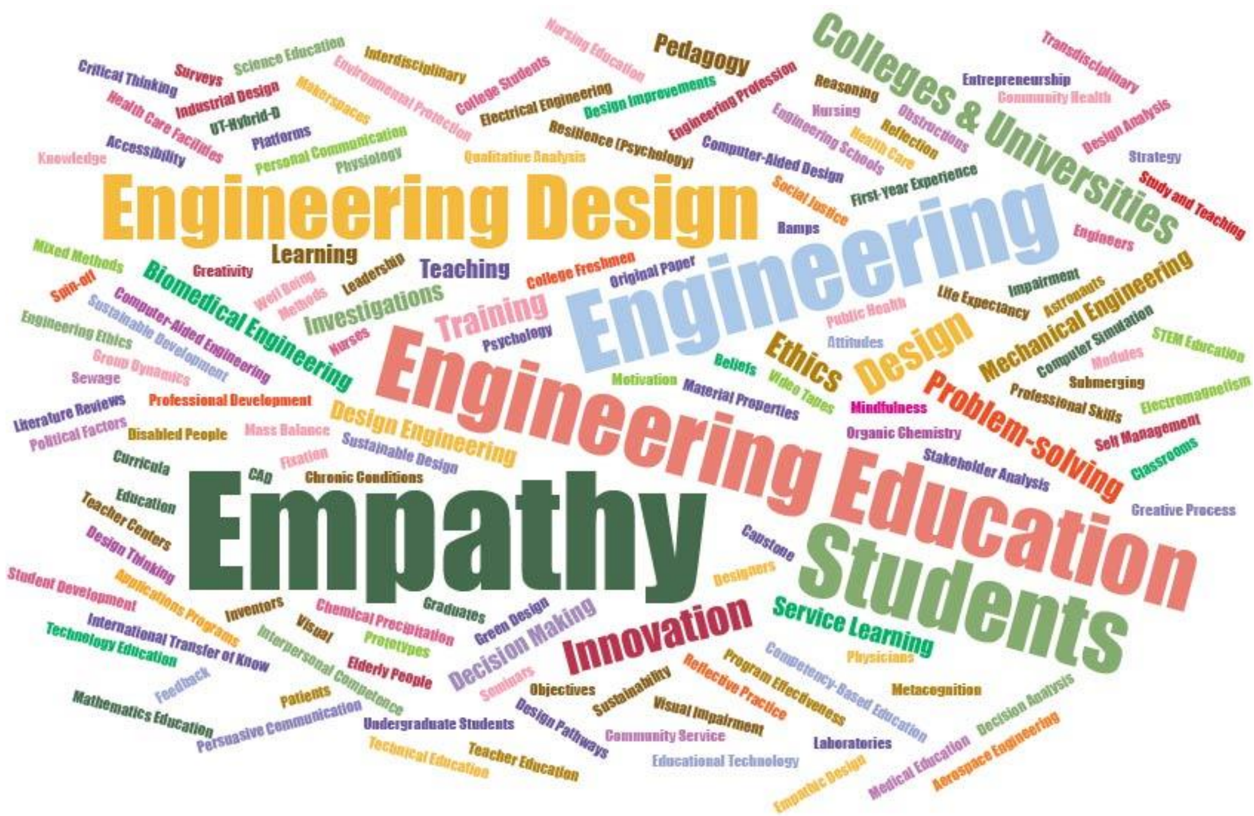

Figure 4: Author indicated subjects for the 15 articles within the Teaching and Learning theme related to undergraduate engineering education. Size gives an indication of subject occurrence.

Three articles were related to first-year engineering courses or extra-curricular offerings. In the article by Dodson et. al. [36], the authors created a trans-disciplinary humanitarian engineering course where students were assigned a “role” through which to consider the design of a waste management system in 1880s Massachusetts. Though the authors provide no measure of empathy changes, the learning objectives of the course were related to ethics, empathy, and social justice. The activities described by the authors, specifically asking students to consider the wastewater problem through the lens of their role and the socioenvironmental context, connect to each of the MEE dimensions, most notably skill- mode switching, orientation- reflective value awareness, and being- holistic service to society. In the study by Prabhu et. al. [35], first year engineering students’ responded to a design prompt to determine connections between their empathy traits and sustainability indicators. While again no empathy training or intervention was provided, the authors identified that students’ “empathic concern correlated positively with their attitudes and intension towards environmental sustainability.[35]” This study is an example of the MEE dimension of being- dignity, worth of people, and the natural environment. These two studies point to an emerging connection between empathy, sustainable, and environmentally conscious thinking. In another study targeting first year engineering students, Huerta and coworkers [37], seeking to improve student intra- and interpersonal competencies, implemented an extra-curricular mindfulness program. Of the 45 students who participated in at least one session, 19 self-reported experiencing greater empathy, one of the interpersonal competencies, along with communication and teamwork/leadership, that the authors hypothesized may be improved by mindfulness training. This study is one of the few articles in this review that connects to the MEE skill of emotion regulation and being whole professionals, indicating mindfulness practices are one way to incorporate these elements into engineering teaching and learning.

Three articles related specifically to undergraduate biomedical engineering. In the article by Allen and Chen [28], the authors taught two versions of an upper level biomedical design course where students were either paired with a specific patient for an accelerated course or were assigned a specific division of the university's medical center for a semester. The authors hypothesized that the full-term class would yield higher quality final products but that the short-term class would produce higher quality initial concepts by deepening students' empathy for the products user. They found, however, that student products in the short-term semester were of a similar quality to those in the long-term course, attributing this in part to increased empathy and motivation as a result of the patient-focus. The activities described in the article paired with the student comments on these activities show connections to all of the constructs of empathy and each of the dimensions of the MEE. Notably, students in the class had to take patient perspectives (skill), display epistemological openness to address patient needs (orientation), and become engineers who acknowledged the dignity and worth of people (being). The primary goal of the biomedically focused article by Hess et. al. [42] was to understand how an imbedded ethics assignment impacted ethical skills and empathy in biomedical students. While no quantitative difference was observed in students after the assignment, qualitative findings indicated that students made connections to the concerns of animals and "grapple[d] with.. emotions in visceral ethical encounters" which connect to both the cognitive and affective constructs of empathy, as well as the orientation and being dimensions of the MEE. Ethical reasoning was also the topic of the article by Lewis, *et. al.* [38] in which both engineering and non-engineering students in an introductory medical design class were pre and post tested using the Survey of Ethical Reasoning. Empathy, which the authors propose is one of 8 components to be considered when facing an ethical dilemma, was introduced and reinforced through both ethical reasoning and design thinking training. While the study had limited findings specific to empathy, the study reiterates the connection between empathy and other durable skills critical for engineers of the future, such as understanding the ethical context of engineering work.

Within the undergraduate engineering curriculum, senior design or capstone courses are a natural place for summative assessment of skills that impact students' design abilities, such as empathic capacity. Several articles were about design courses where empathy or lack of empathy for the end user was seen to impact the design process and design choices. While engineering design is its own theme, the articles here related specifically to capstone design courses. Schmitt et. al. [39] analyzed two capstone design projects where teams were "designing for users the designer lacks empathy for"; in both projects students were designing for differently-abled users, while not themselves differently-abled. This assertion by the authors is misleading, as it seems to indicate that one cannot be empathic regarding someone they are not like. They noted, however, several methods by which students increased their ability to understand (cognitive empathy) and design (behavioral empathy) for the needs of the users such as stakeholder interviews and personas. Ultimately, the two groups studied in the article did not produce solutions that truly met the needs of the users. The authors believed that empathic consideration of the end user needed to be incorporated into early stages and throughout the design process to meet both technical requirements and user needs, calling for tools and methods of increasing empathy to be included in engineering education [39]. In another article by Guanes et. al. [32], the authors interviewed ten senior design students to ascertain their perspectives on empathic approaches in engineering design decisions. While the respondents reported the belief that empathic approaches were valuable, especially as related to considering harmful impacts of designs and meeting users' needs, ultimately the students' design decisions were determined by self-interests, such as time-constraints and instructor input. The authors connect their findings to the orientation dimension of the MEE, specifically discussing how the micro to macro focus could help students consider stakeholders directly and indirectly impacted by their products and how epistemological openness can "allow students to close the gap between their beliefs and behavior about empathy by considering, understanding, and valuing the inclusion of diverse perspectives during the decision-making process [32]."

Service learning courses offer a unique opportunity to train in and evaluate empathy skills, orientations, and values within engineering. Considering a service learning course where students were tasked with creating a universally accessible zipline, authors Hess and Fila [40] outlined the function of empathy throughout the students' design process: developing empathic understanding, identifying user-centered criteria, generating design concepts refined by users, and evaluating design concepts presented to the user. They found that "interestingly, the designers often used criteria generated from their empathic understanding to inform, justify or evaluate technical constraints [40]", which supports the MEE skill of mode switching. In another qualitative study by Wang et. al. [29], a service learning international trip was used as a platform to develop empathy in engineering students. The authors found that empathy could be fostered through "group dynamics, interactions with the community, and individual interpretation of the service-learning experience through self-reflection [29]". Service learning generally provides educational opportunities through addressing the needs of others, which connects to the MEE dimension of being elements of holistic service to society, and the dignity and worth of people and the natural environment.

While many articles in this category studied empathy combined with other skills (i.e. ethical reasoning or mindfulness) or from a design or service learning perspective, three articles sought specifically to develop empathy trainings within their engineering curriculum. Notably, in an article by the author of the MEE, Walther et. al. [27] discuss four modules created to introduce engineering students to each dimension of the MEE. The activities outlined require a level of vulnerability and emotion not typically experienced or observed in an engineering classroom. The authors' discussion spoke specifically to this challenge regarding the instructional culture of engineering, stating that the activities may be "outside of engineering students' comfort zone [27]". Similarly, Rivas and Husein [34], reported experiencing a wide range of student responses to incorporating empathy training into engineering courses ranging from personally engaged to critical. However, the modules presented in the Walther article [27] and the example assignments provided in the Rivas article [34] are instances of introducing students to the socio-technical nature of engineering, which could be of use to other engineering educators. Shannon *et. al.* [31] designed three Electromagnetics courses to explore student empathic cycles, seeking to train in empathy through modeling empathy in their own behavior, behavioral empathy. In the study, however, empathy was defined as an ability to understand how others feel, connecting to cognitive empathy, and was mapped to reflections regarding students' appreciation, which was tied to statements expressing "students' ability to recognize and understand the professor and the professor's teaching practices [31]". The authors presented a model for user-centered engineering that builds off self and other awareness (MEE skill element) to listen, resonate with, connect, and detach from clients (MEE skill- mode switching). While the pedagogical approach of modeling empathy in the engineering classroom is commendable, the connection between student appreciation of the professor's teaching practices and empathetic capabilities is unclear and more evidence supporting the authors findings and their proposed model is needed to encourage its use by other engineering educators. As a collective, the articles point to affective empathy potentially being the most difficult construct to train in for engineering students.

Two articles related to considering empathy in the education of engineering or STEM educators [30], [41]. Both articles were limited in scope, presenting findings from only one class each. In the article by Cheek *et. al.*[30], the authors proposed that the addition of an empathetic character in engineering design problems may increase creativity. While their finding was exactly opposite, i.e. the addition of an empathetic actor resulted in greater similarities in designs, the authors unknowingly produced anxiety in their students by having the empathetic character remain in the class for the duration of the design period. This study had very limited connections to the constructs of empathy or the MEE. The article by Tanu *et. al.*[41] was unique in its focus on the affective construct of empathy, desiring to understand how considering the emotions of students could improve instructional design. While considering the emotions of engineering students could likely improve instructional design and is an area deserving further research, the authors were unable to provide any actionable conclusions.

Graduate

Only four articles were found that related to empathy in graduate engineering education, shown in Table 3. The author indicated subjects of these four articles are shown in Figure 5, which show that ethics, design, and perspective taking were the focus of multiple articles in this section. In two articles by the same first author [42], [43], the authors probe the development and changes of graduate student's perspective taking and ethical reasoning during an engineering ethics course. Using a SIRA (scaffolded, interactive, and reflective analysis) learning framework of ethical case studies, the authors observed increased perspective-taking tendencies. While these articles are clearly related to the MEE dimension of skill- perspective taking, they also connect to the orientation and being dimensions through the use of reflexive principlism, which considers beneficence, nonmaleficence, respect for autonomy, and justice as the ethical reasoning lens. In the third article of this category by Gray et. al. [44], the authors introduced an "empathic walkthrough" in engineering and industrial design classes, half of which were graduate classes, where students worked in dyads to tell the story of a potential user to help generate design ideas. The authors believe they observed students obtaining a deeper understanding of problems users may encounter through story telling during design ideation. This study connects to cognitive and affective empathy and the MEE dimension of empathy as a skill. In the study by Surma-aho *et. al.* [45], the perspective taking tendencies of graduate students in a global multidisciplinary design class focused on industry projects was measured at the beginning and conclusion of the class. While no empathy training was provided, student's self-reported perspective taking tendencies increased, potentially due to exposure to global industry projects. The authors express that a limitation of their study is that they measured "everyday" perspective taking tendencies, which may not correlate to the engineering design setting, providing antidotal support for the need for our research team's work to develop an EES.

Table 3: Title, category, empathy constructs, and MEE elements for the 4 articles related to the Empathy in Graduate Teaching and Learning Engineering.

Title	Empathy Construct	Connection to the Model of Empathy in Engineering
Assessing the Development of Empathy and Innovation Attitudes in a Project-based Engineering Design Course [45]	cognitive, affective	Skill- Perspective Taking
Enhancing engineering students' ethical reasoning: Situating reflexive principlism within the SIRA framework [42]	cognitive, behavioral	Orientation-Micro to Macro Focus, Reflective Value Awareness, Commitment to Values Pluralism Being- Dignity, Worth of People, & Natural Environment
Idea Generation Through Empathy: Reimagining the 'Cognitive Walkthrough' [44]	cognitive, affective	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness
The Development of Empathic Perspective-Taking in an Engineering Ethics Course [43]	cognitive	Skill- Perspective Taking Orientation-Micro to Macro Focus, Reflective Value Awareness, Commitment to Values Pluralism Being- Dignity, Worth of People, & Natural Environment

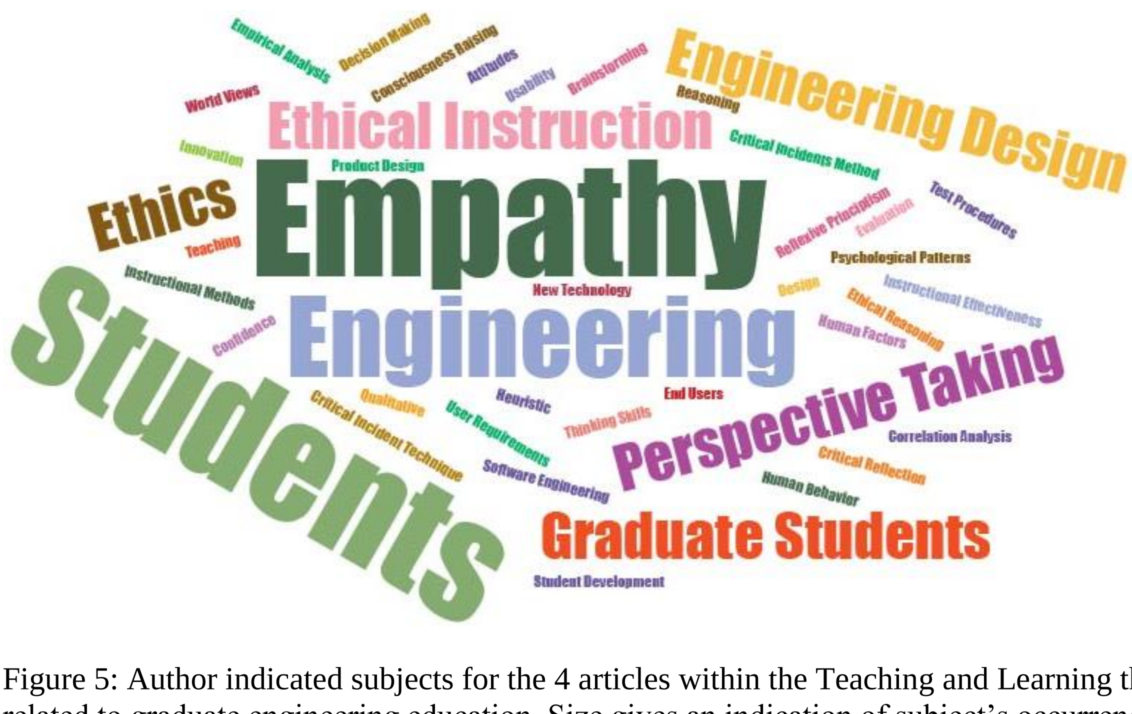

Figure 5: Author indicated subjects for the 4 articles within the Teaching and Learning theme related to graduate engineering education. Size gives an indication of subject's occurrence.

K-12

The title, empathy constructs, and MEE elements of the 6 articles related to Empathy in K-12 Teaching and Learning of Engineering are shown in Table 4. The word cloud of Figure 6 shows that common foci of this section were science, technology, engineering, and math education, which emphasizes the connected nature in which the STEM disciplines are taught at the K-12 level. Also displayed prominently is design, showing that this key practice of engineering is being integrated into K-12 curriculum. The six articles focusing on K-12 education stretched across grades K-8 only, with four of the six articles focused on upper elementary (grades 4-5) and middle grades (grades 6-8). One study involved Kindergarten students only and one article focused on lesson creation of teachers in elementary grades (grades K-5). Each of the six articles looked at empathy in engineering and/or STEM or STEAM, but with an overall focus of design engineering.

Table 4: Title, category, empathy constructs, and MEE elements for the 6 articles related to the Empathy in K-12 Teaching and Learning Engineering.

Title	Empathy Construct	Connection to the Model of Empathy in Engineering
Context mapping in primary design and technology education: a fruitful method to develop empathy for and insight in user needs [46]	cognitive, affective, behavioral	Skill- Perspective Taking Being- Dignity, Worth of People, & Natural Environment
Equitizing Engineering Education by Valuing Children's Assets: Including Empathy and an Ethic of Care When Considering Tradeoffs after Design Failures [47]	cognitive, affective, behavioral	Skill- Perspective Taking, Self & Other Awareness Being- Dignity, Worth of People, & Natural Environment
Infusing Empathy Into Engineering Design: Supporting Under-represented Student Interest and Sense of Belongingness [48]	cognitive, affective, behavioral	Skill- Self & Other Awareness Orientation- Reflective Values Awareness
Observing Empathy in Informal Engineering Activities with Girls Ages 7–14 [49]	cognitive, affective, behavioral	Skill- Perspective Taking Orientation-Micro to Macro Focus, Reflective Value Awareness Being- Whole Profession
Planning a Novel Engineering Unit: Literacy Connections [50]	cognitive, affective, behavioral	Skill- Perspective Taking, Self & Other Awareness, Affective Sharing Orientation-Micro to Macro Focus, Reflective Value Awareness, Commitment to Values Pluralism Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment
The power of building empathy in STEAM [51]	cognitive, affective, behavioral	Being- Holistic Service to Society, Dignity, Worth of People, & Natural Environment

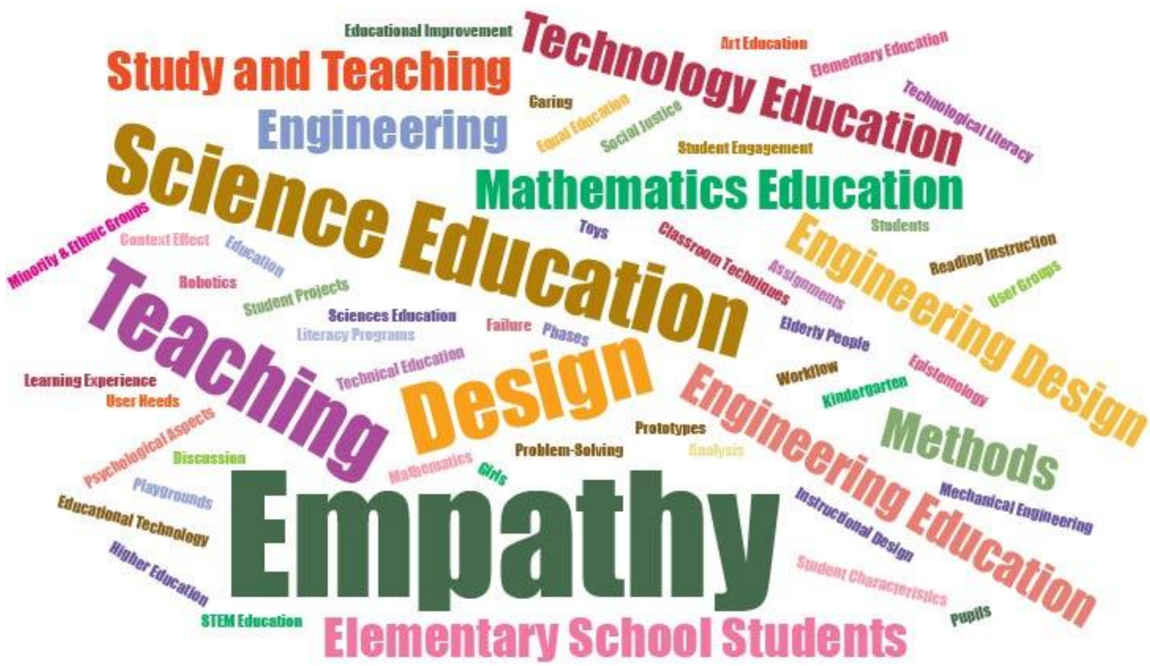

Figure 6: Author indicated subjects for the 6 articles within the Teaching and Learning theme related to K-12 engineering education. Size gives an indication of subject's occurrence.

One study's focus was teachers teaching empathy through design thinking [51]. This study did not designate a particular age or grade level, but was published in The Elementary STEM Journal so it can be assumed that the authors were referring to elementary or K-5 teachers. This article used "The Design Thinking Framework" [48], [51] to help teachers understand the importance of empathy in their transdisciplinary instruction. The article was more of an informative article for teachers to assist them in lesson plan creation with the focus on STEAM and empathy specifically and discussed all three constructs of empathy and being- holistic service to society, dignity, worth of people, and natural environment in the MEE. Another article also utilized the "Stanford 4D Design Thinking Process Model" in their study focusing on middle grades[48]. In this study of 12 diverse middle grade students in a science club after-school program the study used various STEM lesson plans and followed the Stanford Design Model with each lesson or activity ending with an open-ended student survey that focused on empathy, interest, and sense of belongingness. Although because of the size and limitations of this study no concluding results could be determined, the researchers believe that this study is a good stepping stone for connecting empathy and STEM education in future research and does highlight all three components of empathy and skill- self and other awareness and orientation- reflective values awareness in the MEE

Five of the six articles used a specific lesson plan focus for their studies. Lottero-Perdue and Settlage [47] concentrate their study on Kindergarten students and design. 53 Kindergarteners from three different elementary schools created a fence using blocks to keep a small toy robot, Henrietta, contained. Students were also individually interviewed to help understand their decision making in their creations. This study's literature review was more extensive in their unpacking of the three components of empathy and how that can benefit design. Through the interviews the researchers found evidence of empathy and care for "Henrietta" and how this impacted the kindergarteners' fence design. The researchers focused on Cunningham and Kelly's (2017) [52] sixteen epistemic practices of engineering and specifically on "making trade-offs between criteria and constraints[47]." In Letourneau, Bennet, and Liu [49], they conducted a three-year study at a science center in the US and developed six engineering activities that used narratives and tested these activities on 245 girls ages 7-14 (or upper elementary and middle grades). Because women are underrepresented in STEM, the study focused on the use of narratives to enhance aspects of empathy (affective responses, mode switching, and cognitive perspective-taking) in engineering activities with the goal of using design problem solving to help others as a way to interest more girls at a younger age in STEM. In the book Novel Engineering [50], Chapter 8 is a case-study of one fifth-grade teachers experience teaching a book in which the main character was deaf and self-conscious about her hearing aids. The students were then asked to think about the problem from the main character's perspective and design a hearing aid that would be less obvious. The case study looks at the use of empathy and compassion in product design specifically focused on skill- perspective taking, self & other awareness and being- dignity, worth of people, and natural environment from the MEE. The sixth study focused on 20 students ages 9-12, again upper elementary and middle grades, and used the case-study approach as well [46]. The students were asked to design a playground for both children and elderly people so that they could all move together freely. The study focused on human-centered design and context mapping to help utilize empathy and perspective-taking in their case study and found that students were able to consider others as they designed their playgrounds at this young age that again focused on skill- perspective taking and being- dignity, worth of people, and natural environment from the MEE

Design

Of the 48 articles included in this review, six were considered as falling mainly into the theme of Empathy in Engineering Design, shown in Table 5. Elements of design, design thinking, and human-centered-design were found in many of the articles in the previous two sections. The articles included in this section address design as an integral part of engineering practice and industry. While members of many other fields can be designers and often those outside of engineering are involved in the engineering design process, here, we considered only articles where design was being addressed within the engineering context. As the design theme contains the fewest number of articles, only two distinct categories were used to group the articles, product development (n= 3) and users/customers (n= 3), which were aligned with two prominent words in Figure 7, the word cloud showing the subjects of these six articles. Notable, five of the six articles originate from outside the United States.

Table 5: Title, category, empathy constructs, and MEE elements for the 6 articles related to the Empathy in Design.

Title	Category	Empathy Construct	Connection to the Model of Empathy in Engineering
A context analysis method for empathy in co-creative innovation	Product Development	cognitive, behavioral	Skill- Perspective Taking Orientation- Epistemological Openness, Reflective Value Awareness Being- Whole Profession
Challenges of Doing Empathic Design: Experiences from Industry	Product Development	cognitive, affective, behavioral	Skill- Perspective Taking Orientation- Epistemological Openness, Commitment to Values Pluralism
From Product Development to Innovation	Product Development	cognitive	Skill- Perspective Taking
A framework for empathy in design: stepping into and out of the user's life	Users/ Customers	cognitive, behavioral	Skill- all elements
Empathic engineering: helping deliver dignity through design	Users/ Customers	cognitive, behavioral	Being- Dignity, Worth of People & Natural Environment
Understanding customers across national cultures: the influence of national cultural differences on designers' empathic accuracy	Users/ Customers	cognitive	Skill- Perspective Taking, Affective Sharing, Self & Other Awareness

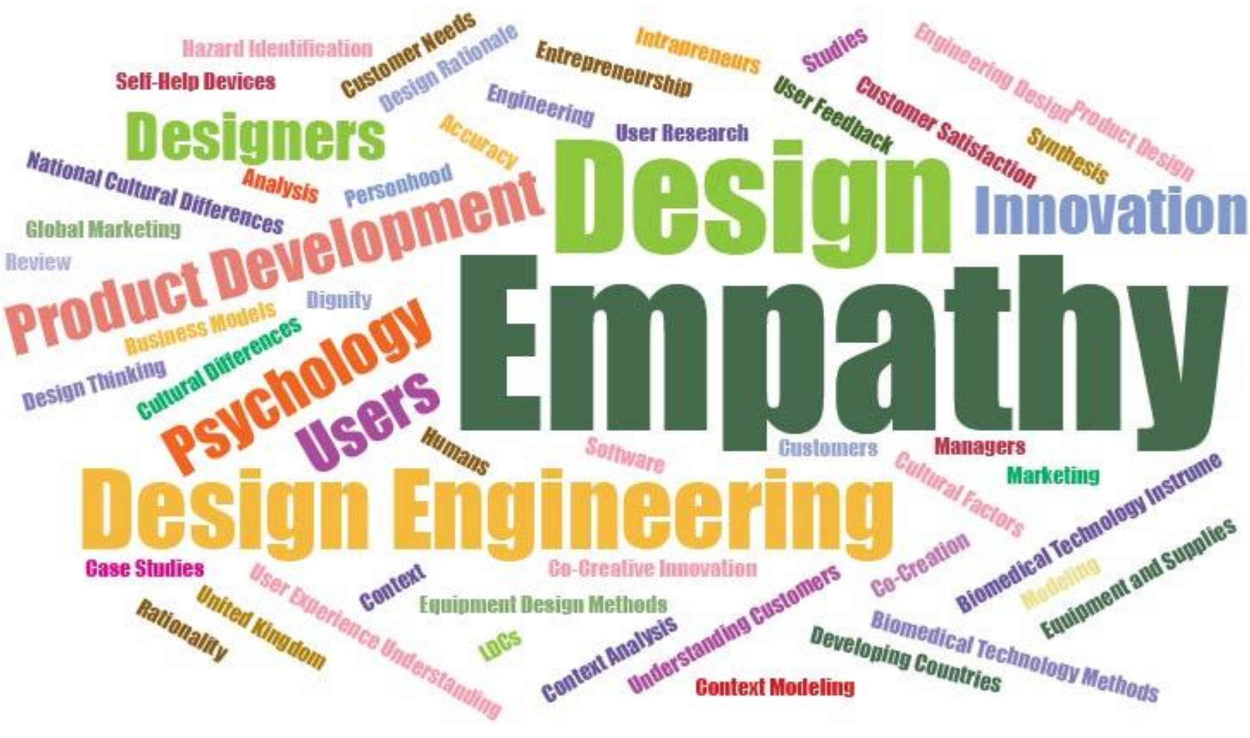

Figure 7: Author indicated subjects for the 6 articles within the Design theme. Size gives an indication of subject occurrence.

Product Development

There were three articles related to employing empathy within the new product development (NPD) context. In the article by Tsutsui et. al. [53], which presents a case study for design of a therapy robot, empathy is defined as mutual understanding of others which allows for assimilation. Here the authors focus on the cognitive and behavioral constructs of empathy, neglecting the affective. The author's ideas of how co-creative and innovative NPD is conducted involves the MEE skill of perspective taking and orientation of epistemological openness and reflective value awareness, as co-creators seek to understanding other co-creators' intentions and goals. In the article by McMahon [54], empathy is discussed as being critical to initial steps in the design process, connecting to the cognitive construct of empathy and the MEE skill of perspective taking. In the article by Postma et. al. [55], the authors share insight from an industry case study of NPD for baby care. The authors desired to implement empathetic design into their NPD process, but found many challenges related to using research insights related to feelings in NPD, teaming, and organizational culture. The case study the authors discussed in the article showed all of the constructs of empathy and related to both the skill and orientation dimensions of the MEE.

Users

Three articles related to user/customer empathy in engineering design. The earliest article in this section by Kouprie and Visser presents a framework for applying principles of empathy from psychology to the engineering design process, guided by the question "How does the design team make appropriate design choices for others who are unlike themselves?"[56]. The phases of their framework are (1) discovery, "entering the users world" (2) immersion, "wandering around the user's world" (3) connection, "resonating with the user" and (4) detachment, "stepping back into the role of designer"[56]. This framework incorporates all of the constructs of empathy, and each of the MEE skill elements of Affective Sharing, Self & Other Awareness, Perspective Taking, Emotion Regulation, (1-3) and Mode Switching (4). This framework does not, however, address MEE related to orientation or being. The article by Hosking, *et. al.*, [57] however, is an example of the being dimension of the MEE highlighting the dignity and worth of people and the environment. In the article, the authors explore how the use of empathy tools, such as devices that limit a designer's abilities or simulations of impairment, can help those designers produce solutions that preserve dignity. In the study by Li, *et. al.* [58], the research team studied the impact of cultural differences on a designer's empathetic accuracy using semi-structured interviews conducted in a laboratory setting. They found that designers had higher empathetic accuracy with potential customers of the same nationality. To assess empathetic accuracy, the researchers asked the designers to watch videos of potential customer interviews and record what they believed the potential customer was thinking and the associated emotional tone. These activities, which primarily related to cognitive empathy, are examples of perspective taking and affective sharing, which are two of the skill components of the MEE.

Implications for Future Research

Within the theme of the Role of Empathy in Engineering, there is more to be explored regarding the role empathy plays in the gendered experience of engineering. While studies are beginning to uncover ways empathy perceptions may be impacting choosing engineering as a profession, further studies are needed to understand whether empathy perceptions impact sense of belonging and engineering identity formation among women in engineering. Additionally, understanding the impact of these perceptions at each life stage many help recruitment and retention efforts of women in engineering.

Despite teaching and learning engineering empathy being the largest theme in the literature, many areas of future research still exist in this theme; we highlight three here. First, no articles were found related to teaching and learning in continued education or professional development classes. As many of the teaching and learning articles made connections between empathy and engineering ethics, researching ethical trainings professional development courses, such as those offered by the National Society of Professional Engineers, connections to and impact on empathy capabilities would address this gap. Second, the MEE skill of emotion regulation was addressed in the article regarding mindfulness training [37], but largely missing from the rest of the literature. There is an important gap to fill related to the role of emotion in engineering teaching, learning, and practice, especially related to understanding, feeling, and addressing the emotions of others. Third, we did not find any studies that probed empathy and followed engineering students longitudinally through their formation. While such a study would necessitate a patience non-tenured engineering faculty do not have the luxury of, such a study would provide rich insight into where empathetic interventions would be most beneficial for preventing the observed unlearning of empathy in collegiate engineering formation [4].

Implications for Teaching

As those privileged with shaping future engineers, engineering educators must begin, or more likely continue more fully, modeling and supporting each dimension of the MEE for perceptions of the empathetic nature of engineering to change. Each educator should answer for themselves questions such as when do I practice mode switching, how can I be more aware of the competing values of engineering work, and how can I demonstrate being a whole professional in the classroom? Three practical ways of integrating empathy into engineering courses follow: engineering-in-place, stakeholder role play, and vocalized mode switching. First, while service learning trips may present a financial burden to students, benefits to empathy formation through service engineering may be possible in a local or short-term setting. Educators should consider how to teach engineering-in-place, where the problems of their local community, or even department, become the focus of design projects and capstones. The first author incorporated this into one of her junior level labs by asking them to redesign and prototype a new circuit board to be used in the physics labs by non-engineering or physics majors. Students were able to observe users of the old circuit boards and interview stakeholders to formulate a list of requirements, allowing them to practice the MEE skill of perspective taking and affective sharing and orientation of epistemological openness. Second, incorporating role play activities into design and other engineering courses provides a low barrier to enter the avenue to many of the MEE skills, orientations, and ways of being as demonstrated in the article by Dodson and coworkers [36]. Lastly, vocalized mode switching can serve as a way to both model empathetic capabilities relevant to engineering, and affirming students' thoughts and emotions. This activity could take on many forms, for example acknowledging the experience of negative emotions such as fear when encountering a new thermodynamics problem, then pointing students to the knowledge they likely already have regarding energy conservation.

Implications for Practice

The call for the embedding of empathy in engineering cannot end at engineering education and research, it must continue to the culture and practice of engineering in industry.

The design section of this review showcases a few articles that demonstrate ways empathy is being thought about and practiced in industry, particularly as it relates to user needs and product development. One of the MEE elements most missing, however, from the literature was being a whole professional. This lack can only fully be addressed by questioning and understanding engineering professional practice. We must ask and answer questions such as how can engineers demonstrate being whole professionals in the work place? And would such demonstrations be welcomed?

In a world greatly divided on both what societal problems are and what solutions to those problems should be, empathizing with those not like oneself is highly difficult. Engineers, however, must find ways to be empathic with those not like themselves to holistically serve society. Pulling from this literature review and the MEE, we point to three things to aid practicing engineers as they empathize with those not like themselves. First, in the education literature, narratives and role play were used to introduce students to others' perspectives and needs; this activity could be incorporated into problem defining and solution brainstorming in industry. Second, in the article by Li, *et. al.* [58], researcher found that cultural differences impacted a designers ability to determine what a customer was thinking; as engineering industry becomes increasingly global in nature, practitioners must keep this in mind. Holding to the MEE orientation elements of reflective value awareness, commitment to values pluralism, and epistemological openness can allow engineers to serve the needs of diverse cultures. Lastly, in the article by Hosking, *et. al.*, [57] the authors consider the use of empathy tools, devices that simulate impairments, to understand the perspectives of those differently-abled than oneself, highlighting one way technology can aid empathetic engineering. Virtual reality could be used as another route to putting engineering in the shoes of another.

Future Work

As indicated in the introduction, this research is part of a larger project focused on the creation of an Engineering Empathy Scale (EES). While there is foundational research to describe the views of engineers regarding empathy[3]–[6] and a Model for Empathy in Engineering (MEE) [13], there are fewer studies describing scenarios of empathetic displays within engineering practice and education and no quantitative scale to assess an engineer's empathetic abilities in engineering specific scenarios. To address these gaps in engineering formation research, our future work will be guided by the following research questions:

RQ1: How is empathy conceptually perceived, experienced, and shown in engineering specific situations?

RQ2: Can engineering specific situations be used to measure empathy in engineering students, faculty, and practitioners?

Using the three constructs of empathy and the model for empathy in engineering as theoretical framework, the research team has conducted semi-structured focus groups with practicing engineers and engineering faculty to obtain detailed descriptions of empathetic thoughts, emotions, and displays within the specific context of engineering practice and education activities. Currently, the research team is analyzing this data to extract themes which will be used to develop a large set of questions, $Q \geq 70$, regarding empathy in engineering specific scenarios. This initial question set will go through expert and novice review. Coding agreement between panel members will be used to select the question set for initial validation. Initial validation and reliability of the EES will be determined through confirmatory factor analysis of engineering students, $N \geq 300$. Once the EES has gone through initial validation, the research team will make the scale freely available to engineering educators and industry representatives who wish to use it to benchmark empathy teaching and training initiatives for the engineering enterprise.

Conclusion

Through this systematic review, we have found that the representation and perceptions regarding empathy in engineering are varied, from an intrinsic aspect of the engineering discipline, to a lacking component that may be keeping women from pursing engineering. Each of the dimensions of the MEE were found within the existing engineering empathy literature, providing support for our research team's use of it as a guiding framework for our EES creation. However, assessments of empathy were largely qualitative or used general empathy scales that did not connect to each of the empathy constructs. Surma-aho and coworkers noticed the "difficulty of using scales with general language in a context-specific situation [45]" as they sought to measure changes in perspective taking in engineering graduate students. Our research teams' EES will use engineering specific scenarios, overcoming one of the current issues in engineering formation, a disconnect between a knowledge of empathy generally and its role within the discipline of engineering. The EES will allow for engineering empathy to be benchmarked, tracked, and grown. While the current literature supports each dimension of the MEE, the skills of emotion regulation and mode switching, the orientation of micro to macro focus, and the way of being a whole professional deserve to be more fully explored as they were only observed in a small portion of the literature. By increasing empathetic capabilities, engineers will be better able to understand the context, values, and driving forces of their work and relate to and communicate with those impacted by their work. Overall, these traits will allow engineers to better holistically serve society.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Award No. 2306271. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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