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Board 175: Poster: Strategies for Empathy Instruction and Assessment in Biomedical Engineering Education: A Review

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Strategies for Empathy Instruction and Assessment in Biomedical Engineering Education

Abstract

Empathy is being recognized as an important skill in engineering practice and design as engineering becomes globalized and seeks to solve complex sociotechnical problems. Empathy is particularly important in biomedical engineering (BME) because of the inherent sociotechnical nature of the discipline and the high-stakes impact BME has on people through healthcare and medicine. Empathy has been operationalized in engineering education as perspective-taking to teach students to consider diverse stakeholder needs and points of view in engineering design. However, perspective-taking is only one facet of empathy. This work reviews models of empathy, pedagogical strategies for empathy education, and empathy assessments that have been employed in the context of BME education to enable BME instructors to integrate empathy education in their individual course contexts and continue to develop empathy education within BME education.

Keywords: Empathy, Biomedical Engineering, Undergraduate

Introduction

As the world has become increasingly global, so too has engineering become a global practice, requiring engineers to have diverse social and technical skillsets [1]. This is particularly important as modern-day engineers are expected to participate and problem-solve within sociotechnical challenges such as climate change, healthcare, and food insecurity [2]. To solve these complex problems, engineers must understand the societal impacts of their engineering designs on multiple stakeholders. The importance of social impact in engineering is reflected in the required student outcomes set by the Accreditation Board for Engineering and Technology (ABET). Student outcome two in the second criterion states that graduates should have “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors” [3]. Engineering students can learn to incorporate these factors in their designs and consider stakeholder needs by practicing empathy, which has been operationalized in engineering design as perspective-taking. The ability to step into the perspectives of others allows engineers to produce sound technical solutions that have a positive societal impact and limit potential harm. This skill is particularly important in BME because biomedical engineers are often positioned more closely to their stakeholders (such as patients and doctors) than other engineering disciplines. Furthermore, BME has a direct, high-stakes impact on people through medicine and healthcare, making empathy an important consideration in biomedical design to prevent harm. In addition to perspective-taking, researchers have begun integrating facets of empathy into BME education based on various models of empathy [4], [5], [6] to capture and facilitate holistic empathy development.

This exploratory review aims to summarize and synthesize empathy-focused instructional activities and assessments in undergraduate BME education. While there is a large body of literature regarding empathy education in STEM [7], this review will review empathy models, instructional activities, and assessments that have been implemented specifically in the context of biomedical engineering. This scope provides discipline-specific insight for BME educators and will highlight gaps in empathy education research in BME. However, no single educational activity or assessment can serve as the gold standard, but research has shown that empathy education is most effective when it is incorporated continuously and holistically within a program of instruction [8]. Thus, the goal of this literature review does not assess the utility of empathy activities and assessments. Rather, this review is a resource for BME educators to incorporate activities and assessments to support empathy development in their courses.

Methods

To gather a breadth of strategies for empathy instruction in biomedical engineering, papers were selected from various engineering education conferences or journals, including the *Journal of Engineering Education (JEE)*, the *American Society for Engineering Education (ASEE)*, *Biomedical Engineering Education*, and the *Biomedical Engineering Society (BMES)*. Keyword search terms included "empathy", "biomedical engineering", and "engineering". Papers were vetted and selected by the author if they discussed empathy education and/or assessment in the context of undergraduate BME education.

Empathy Models and Frameworks

Empathy is complex and abstract, which presents a barrier for teaching empathy in the context of engineering and engineering education. To provide readers with a robust understanding of empathy in the context of engineering education, I will discuss empathy models that have been applied to BME education in the literature covered by this review. Two models were developed in the context of engineering education [4], [5], and one model developed in psychology has been applied in BME education research [6]. It is important to state that no model will fully encompass all the nuances of empathy. However, discussing various empathy models will serve as a conceptual basis for researchers and educators to consider empathy in educational contexts and will situate the learning activities and assessments discussed later.

Zaki's Model of Empathy

The psychologist Jamil Zaki developed a model of empathy composed of three interrelated components: *sharing* (emotional), *thinking about* (cognitive), and *caring about* (motivational) [6] (see Figure 1 which provides a visualization of each model discussed). *Sharing* is defined as noticing and engaging with someone else's emotions and can be recognized as taking on another's emotions: sharing experiences, emotional empathy, and personal distress. *Thinking about* is the cognitive facet of empathy, what psychologists often call mentalizing, and is defined as intentionally and explicitly trying to understand someone else's perspective. The final component, *caring about*, harnesses the other two facets of empathy into action. *Caring about* is the motivation to help someone else and can also be referred to as empathic concern. Each component of Zaki's model represents different manifestations of empathy and each serve to reinforce the others. For example, *sharing* another's emotions often prompts concern for them, or *caring about.* Each component is also present to different degrees within different contexts and individuals, but all must be considered and fostered to develop deep empathy. In engineering, the surface level of *caring about* is often represented, as many engineers justify designs by improving wellbeing or problem-solving. However, without considering the perspective and emotions of the stakeholders (*thinking about* and *sharing*) the design is at best not as effective as it could be, and at worst, harmful. Each facet of Zaki's model should be considered when including empathy in curricula. As BME engineering educators strive to encourage and teach their students how to practice empathy in engineering, how can each facet of empathy be considered and applied? What problems might arise if only one facet is explicitly considered?

Affective/Cognitive and Self-Oriented/Other-Oriented / Interpersonal Reactivity Index

In seeking to develop a functional definition of empathy from synthesizing literature, Hess and Fila [4] developed a model of empathy categories across four quadrants (Figure 1). Figure 1: affective experiences/cognitive processes and self-oriented/other-oriented. Each quadrant is then defined by its axes. For example, the quadrant defined by affective experiences and other-oriented is empathic concern: feeling for another. This could be analogous to *caring about* in Zaki's model [6]. Indeed, Hess & Fila's model contains each component of Zaki's model. The first quadrant, empathic distress (affective and self-oriented) maps to *sharing* and the two perspective-taking quadrants (cognitive and self and other-oriented) maps to *thinking about.* Additionally, each model emphasizes the interaction between components. Although similar, the models' differing language and structure reflect the context in which they were developed. In describing his model, Zaki uses language common in psychology, situating the user as an observer of empathy. In contrast, Hess and Fila describe each quadrant with gerunds (imagining, feeling, experiencing) which situates the model user as the one practicing empathy, in line with their stated purpose of operationalizing empathy. This model aligns with the empathy types from the Interpersonal Reactivity Index (IRI) [9], an empathy assessment tool in psychology.

High-Level Framework for Empathy-based Engineering Education

While the previous two models focused on universal facets of empathy, the framework developed by Howcroft et al. [5] is a pedagogical model situated in the context of a BME design course case study but intended for broad application in engineering curricula. The goal of this framework is to impress that empathy is a core engineering value and is crucial for success in engineering design. The four pillars of the model (communication, collaboration, decision making, values) are intended to support the integration of empathy throughout a curriculum. Each pillar represents a competency associated with empathy in engineering design. For example, the pillar of communication represents the ability of students to engage with their stakeholders as whole people, rather than as engineering problems. The collaboration pillar supports stakeholders as active and equal partners in the engineering process, rather than people the engineers are 'helping'. Following these two pillars, ethical and empathetic decision making are the third pillar, encouraging engineers to base decisions beyond traditional resource justifications, such as cost and time. Howcroft et al. emphasize that these pillars need to be continuously integrated over the course of a degree program to be impactful.

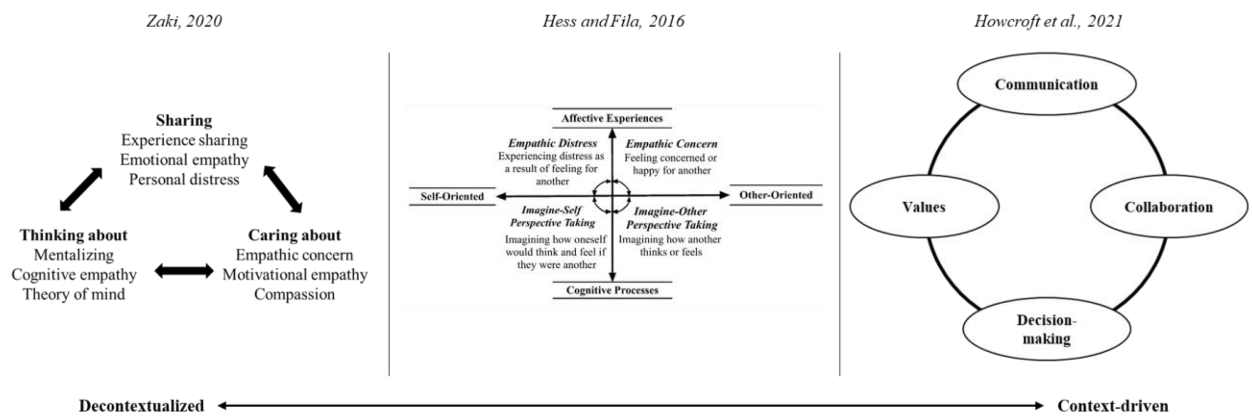

Figure 1: Empathy models adapted from their source literature on a continuum from decontextualized to context-driven.

Discussion

Each model reflects the context in which it was created and can each aid engineering educators in implementing empathy in their curricula. Zaki's [6] model developed by a psychologist, is the most decontextualized of the three: it intends to describe universal facets of empathy outside of the bounds of a specific context and focuses on the individual. Engineering educators can use this model to understand the different ways empathy might manifest in their students during instructional activities and provide feedback to students if they notice one facet of empathy overly represented in student reflections, discussion, or other deliverables. For example, if notices a student only mentalizing (*thinking about*), they might encourage the student to reflect on their own feelings to deepen the exercise (*sharing*). It is particularly valuable to emphasize to students how each facet of empathy is embedded with the others and how each serve to reinforce the other. Hess and Fila's [4] model contains universal facets of empathy, similar to Zaki's, but was developed by engineering education researchers with the goal of functionalizing empathy. This can be seen in the descriptions using action-oriented language, as discussed previously, and in the structure. The axes guide users to categorize empathy activities into quadrants, situating it as a functional tool. Engineering educators can use this model in course design to map instructional activities to the different facets of empathy. By making sure each dimension of empathy is well represented in a course, engineering students are better situated to learn how to practice empathy holistically. Finally, the pedagogical framework developed by Howcroft et al. [5] is a fully context-driven model presented alongside a case study for empathy education in a BME design curriculum. This framework is particularly useful when developing and evaluating a program curriculum. The pillars of this model encourage pedagogy that not only equips students with empathic design skills, but also facilitates values development. The pillars can be traced throughout a curriculum to ensure empathy education is continuously integrated. Therefore, each model can be used to the advantage of engineering educators in a variety of ways and course context should be considered for the selection of a given model.

Pedagogical Strategies

In this section, instructional activities for empathy education that have been implemented in BME courses are discussed. The instructional activities fall into four main categories based on the aspect of BME instruction through which the instructional activity was implemented. For example, reflection was the pedagogical strategy used by Hess et al. [10] in the context of biomedical ethics instruction. Organizing the discussion of pedagogy by the instructional context is useful for BME educators because providing information about the instructional context may help inform choosing and implementing from these strategies to meet individual instructional needs. For example, this structure is useful for educators looking for strategies to incorporate empathy education in specific areas of BME (such as ethics) and/or allows educators to transfer the strategies to similar instructional contexts. The four biomedical educational contexts are: ethics education, empathy in student teams, stakeholder empathy in biomedical design, and personal reflection (Table 1).

Embedding Empathy Instruction Through Ethics Education

One of the most direct ways to introduce empathy education in BME is through ethics education. BME ethics are unique compared to other engineering disciplines because human and animal research are so central. Thus, ethics education in BME can position students to practice empathy in their engineering practice by intentionally considering their research subjects as unique and complex individuals. Additionally, learning to apply empathy in BME ethics is an important skill because misapplication of BME ethics can result in high-stakes harm to human and animal participants. Thus, empathy is not only easily integrated in BME ethics education but can be considered a critical skill for BME students learning to make ethical decisions in the field.

Critical reflection is an instructional method that may facilitate deep student learning and empathy within BME ethics education. Hess, et al. [10], sought to understand how ethics education within a first-year biomedical laboratory course impacted the students' empathy and ethical becoming. This work generated instructional activities to embed empathy through ethics education in a biomedical laboratory course. Empathy was operationalized with the dimensions of empathy (Affective/Cognitive and Self-Oriented/Other-Oriented) previously outlined by Hess & Fila [4]. Hess & Fila [4] designed critical reflection assignments using the DEAL (Describe, Examine, and Articulate Learning) model around animal tissue harvesting. Students reflected in different formats throughout the course: longer written assignments; shorter, 2-3 sentence, reflection prompts; and reflective group discussion with peers facilitated by the instructor. They applied a mixed methods approach to assess student's empathy and ethical becoming before and after the instruction. They used the IRI [9], a quantitative tool to measure empathy constructs, to assess changes in students' empathic disposition. Interestingly, their quantitative findings did not suggest that students' empathy significantly changed by participating in the course. However, thematic analysis of student reflections suggested that the instruction facilitated deep ethics learning, challenging the students to investigate the nuances of animal research ethics and their own emotions. Reflection is grounded in learning science through the concept of metacognition: self-examination of individual learning. By encouraging students to examine their own emotions and learning surrounding BME ethics, Hess, et al. [10] suggest that student learning surrounding empathy and ethical becoming in BME can be supported.

BME education context	*Pedagogical strategy*	*Empathy Model/Framework*
Ethics education	- Critical reflection with the DEAL model applied to tissue harvesting [10] - Ethics in design [5]	- Affective/Cognitive and Self-Oriented/Other-Oriented [4] - High-Level Framework for Empathy-based Engineering Education [5]
Empathy in student teams	- Peer teammate empathy development [11]	- Affective/Cognitive and Self-Oriented/Other-Oriented [4]
Stakeholder empathy in biomedical design	- Empathic innovation workshops [12]	- Interpersonal Reactivity Index model [9]
Personal Reflection	- Story driven learning [13], [14] - Interviews to encourage perspective taking [8]	- Zaki's model of empathy [6]

Table 1: Pedagogical strategies

Howcroft et al. [5] integrated ethics in a BME design course aimed at holistic empathy development in their students towards the stakeholders of the design projects. Students were required to incorporate ethics into their design projects by developing and applying ethics-based and standards-based requirements for their projects and explain how the concept of equity applied to their designs. While this case study did not employ systematic qualitative data collection, researchers observed that students in this cohort had increased empathetic design decision making skills compared to students in previous iterations of the course. More research specifically examining student empathy development due to these instructional methods would support the efficacy of the pedagogy, however, Howcroft et al. [5] present an interesting way to embed empathy instruction in a common BME course. In fact, Howcroft et al. [5] expand the concept of embedding empathy education into BME curricula in the High-Level Framework for Empathy-based Engineering Education they present following their case study, discussed earlier in the Empathy Models section.

Both Hess, et al. [10] and Howcroft et al. [5] use ethics to embed empathy education and ethics in courses that are typical in many BME programs: a first-year laboratory and a biomedical design course. Many engineering curriculum designers and engineering instructors are struggling with content saturation. As the body of engineering knowledge grows, and as the skills requirements for engineers expand, students are expected to be taught and learn more core competencies within the same educational timeframe and with the same number of resources. Often, programs manage adding additional content through an extra class, or even an extra lecture or unit to existing classes to check the box of the requirement. However, tacking on more content can stretch the resources of the instructor and not result in a significant learning experience for students. Thus, when suggesting that another skill, such as empathy, should be incorporated into engineering education, suggesting instructional methods that embed the skill into the existing curriculum can be beneficial. While there is still labor required by instructors to implement the change, holistically embedding skills such as empathy in an engineering curriculum strengthens the existing curriculum and deepens learning by incorporating an important skill into core engineering competencies without contributing to content saturation by adding additional required courses or units. For example, embedding stakeholder empathy and ethics requirements in BME design helped students learn and develop ethical and empathic design skills in a course they were already required to take. Thus, the pedagogical strategies of embedding empathy education in existing, common BME courses through ethics, a required topic in biomedical engineering, show great potential for implementing empathy education into existing BME courses and curricula.

Fostering Peer Empathy in Student Teams

Another way to embed empathy instruction in existing BME education is by facilitating empathy development in student teams. Empathy within student teams has been shown to improve team understanding, creativity, and positivity [11]. In many BME courses, such as laboratories or design, students work in teams with their peers. Hess, et al. [11] studied how empathy manifested in student teams in a BME laboratory course. It is possible for educators to use these findings to support empathy development in student teams, even though this work does not directly look at pedagogy. Hess, et al. [11] coded student interviews with the empathy types in the Affective/Cognitive and Self-Oriented/Other-Oriented model developed by Hess & Fila [4]. They further interpreted their findings through the lens of collective empathy, which examines the relationships between individuals in a group, such as teammates. They observed evidence of peer-to-peer empathy (between individuals) and collective empathy (shared emotions across the whole team). Teammates exhibited cognitive collective empathy by considering each other's perspectives and ultimately developing a shared team perspective. This process could be intentionally supported by learning activities that guide students through sharing their individual perspectives and collaborating on a team mission. Behavioral empathy appeared in student teams through empathic communication, for example, students actively listened to the perspectives of others, gave supportive feedback to their peers, and supported each other in accomplishing design tasks. Behavioral empathy can be encouraged in student teams by the instructor working collaboratively with students to establish empathic behavioral norms in teams. These norms could be committing to hearing all perspectives before making decisions, giving specific and kind feedback, and/or asking for and offering support. Finally, they observed that affective (feeling) empathy manifested in team comfort—positive feelings, and team contagion—diffusion of emotions. Being aware of these empathic processes can help educators guide student teams through conflict, and employing instructional activities that aim to foster empathy in student teams can teach students how to be empathic in teams and increase the positive outcomes of the teams.

Cultivating empathy for stakeholders through biomedical design

Empathy for stakeholders is an important piece of BME design. Kong et al. [12] developed a series of empathic innovation workshops to help students develop empathic design skills. In the first workshop focusing on empathic design, an instructor presented on empathy and students completed a design ideation exercise for visual aid tools. Part of this exercise involved students experiencing challenges of simple, daily tasks while wearing glasses that impacted their vision. The second workshop focused on pivoting and re-framing designs by assessing how well the design could meet stakeholder needs through critical reflection. The workshops culminated with a final session on innovative design that built on the concepts of the previous workshops. Students were provided with a design scenario and stakeholder information was progressively given over the course of the workshop. They assessed empathy with the Empathic Design Tendency Survey, a survey developed for this project based on the Interpersonal Reactivity Index empathy model. They found statistically significant improvement in empathy constructs in students due to the workshops and observed increased student confidence in using empathic design techniques. Additionally, they found that the reframing activities in the workshops increased student empathic tendencies. They recommend that instructors support students in seeking and receiving stakeholder feedback and strategies to help students work through negative emotions associated with the changing design. Finally, they note that providing students with contextual information beyond medical needs supported innovation. This suggests that teaching students to be socially aware of their role and work as engineers beyond technical efficacy is important in developing their empathic design ability. Thus, Kong et al.'s [12] work provides specific instructional activities designed to teach students how to actively incorporate empathic tendencies into their design process.

Eliciting Empathy Through Personal Reflection

While the instructional methods previously discussed are embedded in elements of traditional BME curriculums (design, teamwork, and ethics), Lunn et al. [13] and Morgan et al. [14] describe a standalone BME course based on story-driven learning. In the course "The Art of Telling Your Story", upper-level undergraduate students in BME reflect on their own trajectories and pivotal moments in their lives by responding to story prompts. The pedagogy of story driven learning has previously been used in the context of supporting students in their personal development, but Lunn et al. [13] studied how prompts in this course could elicit the different aspects of empathy articulated in Zaki's model in student reflections. They also compared students' self-perception of empathy to external evaluations of empathy regarding the stories students shared in the class. Using quantitative methods (discussed further in the 'Empathy Assessments' section), their findings suggest that story-driven learning is a pedagogical strategy to facilitate student reflection on each of the components of Zaki's model of empathy: *thinking about*, *sharing*, and *caring about*. Story-driven learning can potentially also be embedded within traditional BME courses, but its impact may be diluted if it is not incorporated to the same degree and frequency as an independent course.

Empathy Assessments

One of the challenges of empathy education and research on empathy education is accurately assessing empathy. No method of empathy assessment is comprehensive or without flaws, but this section describes the tools educators and researchers have applied in BME education to assess student empathy. These assessments can provide insight to educators on the effectiveness of their instructional interventions, and by describing a variety of assessment types, it is possible to triangulate the data collection to support higher quality results.

One empathy assessment tool that has been used in BME education research is the Interpersonal Reactivity Index (IRI) [9]. This tool is a self-report questionnaire developed in the field of psychology to assess different dimensions of empathy (perspective-taking, fantasy or sharing, empathic concern, and personal distress). These dimensions also serve as the basis for the operational model of empathy developed by Hess & Fila [4] (Affective/Cognitive and Self-Oriented/Other-Oriented). Hess, et al. [10] used two dimensions of the IRI, empathic concern and perspective taking, to evaluate empathy changes as a result of ethics instruction. Kong et al. [12] used the IRI as a foundation to design the Empathic Design Tendency Survey, an instrument designed to assess empathic tendencies in engineering contexts. This survey was used to assess empathic design workshops and asks students to self-report on the four dimensions of empathy articulated in the IRI in the context of an engineering design scenario and their own design ideation.

Lunn et al. [13] used a different approach to assess empathy in BME education by developing a rubric based on student artifacts instead of self-report surveys. Using Zaki's model of empathy as the theoretical framework, they developed the External Evaluation of Empathy Rubric (EER) and learning outcomes for cultivating empathy. This rubric intends to offer a more standardized assessment approach than self-report questionnaires, and helps educators assess what components of empathy are present in the artifacts that students produce. Two or three dimensions are provided for each component of Zaki's model. The dimensions are based on personal, individual or group, and societal level. For example, the societal level dimension of 'thinking about' concerns community engagement and change. The instructor can evaluate each dimension on a four-category scale from strongly evident to evident to somewhat evident to not evident.

The self-report questionnaires such as the IRI and the Empathic Design Tendencies Survey are useful for BME educators to assess student self-perception of their abilities with different aspects of empathy. However, they may be more suited to research than informing instruction because they are somewhat removed from instructional activities and student artifacts. While it is possible to ask students to fill out the survey pre- and post- instruction, self-reported data may be difficult to interpret and apply immediately in an instructional context. In contrast, since the EER relies on student artifacts, it may be of higher utility to educators to receive feedback on student learning and adjust their instruction while a course is in progress. The artifacts that the EER was piloted with include user stories (stories considering the perspective of a stakeholder), empathy maps (what a potential user could say, think, feel, and do), formal user needs assessments, and reflective personal narratives.

Conclusion

This review summarized and synthesized models of empathy, pedagogical approaches, and assessment that have been implemented in BME education, including models of empathy, pedagogical methods, and assessments. BME educators can draw on the strategies described in this review to introduce empathy instruction into BME courses and curriculums.

A limitation of this review is that it only examined empathy instruction that had been studied or implemented in the context of BME education. There is a larger body of research broadly regarding empathy education in STEM that may be applicable to BME education. However, more work is needed on adapting and applying general STEM empathy education techniques to be discipline specific to BME because of specific aspects unique to the field, such as clinical human subject research.

Furthermore, research has shown that that engineering students' behavior prioritizes the needs of stakeholders important to them (such as instructors) at the expense of empathic design, even when they are able to explicitly affirm the importance of empathic design [15]. Thus, empathy education in engineering must not only impress upon students the importance of empathy, but it must also consider and challenge the culture and systems at play that compromise empathic decision making in engineering.

More research is needed to generate pedagogical strategies to empower students to be empathic in their role as engineers in the greater context of engineering culture and society.

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References

[1] B. Jesiek, Q. Zhu, S. Woo, J. Thompson, and A. Mazzurco, "Global Engineering Competency in Context: Situations and Behaviors," *Online Journal for Global Engineering Education*, vol. 8, no. 1, Mar. 2014, [Online]. Available: https://digitalcommons.uri.edu/ojgee/vol8/iss1/1

[2] C. Baillie, "Engineers within a Local and Global Society," *Synthesis Lectures on Engineers, Technology and Society*, vol. 1, pp. 1–76, Jan. 2006, doi: 10.2200/S00059ED1V01Y200609ETS002.

[3] "Criteria for Accrediting Engineering Programs, 2022 – 2023 | ABET." Accessed: Sep. 11, 2023. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

[4] J. Hess and N. Fila, "The Development and Growth of Empathy Among Engineering Students," in *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana: ASEE Conferences, Jun. 2016, p. 26120. doi: 10.18260/p.26120.

[5] J. Howcroft, K. Mercer, and J. Boger, "DEVELOPING ETHICAL ENGINEERS WITH EMPATHY," *Proceedings of the Canadian Engineering Education Association (CEEA)*, Jun. 2021, doi: 10.24908/pceea.vi0.14856.

[6] J. Zaki, *The war for kindness: building empathy in a fractured world*, Broadway Books trade paperback edition. New York: Broadway Books, 2020.

[7] E. Wilson and P. Mukhopadhyaya, "Role of Empathy in Engineering Education and Practice in North America," *Education Sciences*, vol. 12, no. 6, Art. no. 6, Jun. 2022, doi: 10.3390/educsci12060420.

[8] S. J. Lunn, C. L. Bell-Huff, and J. M. Le Doux, "Learning to Care: Faculty Perspectives on Developing Empathy and Inclusive Mindsets in Biomedical Engineering," *Biomed Eng Education*, vol. 2, no. 2, pp. 123–140, Sep. 2022, doi: 10.1007/s43683-022-00077-0.

[9] M. H. Davis, "Measuring individual differences in empathy: Evidence for a multidimensional approach.," *Journal of Personality and Social Psychology*, vol. 44, no. 1, pp. 113–126, Jan. 1983, doi: 10.1037/0022-3514.44.1.113.

[10] J. Hess, S. Miller, S. Higbee, G. A. Fore, and J. Wallace, "Empathy and ethical becoming in biomedical engineering education: a mixed methods study of an animal tissue harvesting laboratory," *Australasian Journal of Engineering Education*, vol. 26, no. 1, pp. 127–137, Jan. 2021, doi: 10.1080/22054952.2020.1796045.

[11] J. Hess, A. Carrillo-Fernandez, N. D. Fila, and C. T. Schimpf, "Exploring How Empathy Manifests with/for Teammates in a Junior-Level Biomedical Engineering Course," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Sep. 11, 2023. [Online]. Available: https://peer.asee.org/exploring-how-empathy-manifests-with-for-teammates-in-a-junior-level-biomedical-engineering-course

[12] N. Kong, S. Purzer, L. B. Payne, E. Kim, and C. Vivas-Valencia, "Research Initiation: Enhancing the Learning Outcomes of Empathic Innovation in Biomedical Engineering Senior Design Projects," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Sep. 11, 2023. [Online]. Available: https://peer.asee.org/research-initiation-enhancing-the-learning-outcomes-of-empathic-innovation-in-biomedical-engineering-senior-design-projects

[13] S. J. Lunn, C. L. Bell-Huff, and J. M. LeDoux, “Story-Driven Learning in Biomedical Engineering: Quantifying Empathy in the Context of Prompts and Perceptions,” presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. Accessed: Sep. 11, 2023. [Online]. Available: https://peer.asee.org/story-driven-learning-in-biomedical-engineering-quantifying-empathy-in-the-context-of-prompts-and-perceptions

[14] K. L. Morgan, C. L. Bell-Huff, J. Shaffer, and J. M. LeDoux, “Story-Driven Learning: A Pedagogical Approach for Promoting Students’ Self-Awareness and Empathy for Others,” presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Oct. 19, 2023. [Online]. Available: https://peer.asee.org/story-driven-learning-a-pedagogical-approach-for-promoting-students-self-awareness-and-empathy-for-others

[15] G. Guanes, L. Wang, D. A. Delaine, and E. Dringenberg, “Empathic approaches in engineering capstone design projects: student beliefs and reported behaviour,” *European Journal of Engineering Education*, vol. 47, no. 3, pp. 429–445, May 2022, doi: 10.1080/03043797.2021.1927989.