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The use of healthcare disparities as a tool to teach BME undergraduates about the importance of social justice in biomedical design.

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Abstract

Given the significant impact biomedical engineers make in healthcare and society, it is imperative that engineering students learn to practice empathy, ethics, inclusivity, and social justice to their technical work in order to produce more accessible and socially just solutions to today's complex challenges. A structured curriculum was developed and implemented in a physiology core course within a biomedical engineering undergraduate program that uses healthcare disparities as a tool to teach students how social justice can be integrated into problem-solving. This curriculum includes the following components: 1) in-lecture discussions of specific healthcare disparities and inequities that exist that relate to the organ system being discussed, 2) discussion questions designed to help students learn to socially contextualize technical problems in BME, 3) three equity and ethics assignments, and 4) two team projects: a) one asking teams to design a brain computer interface and address any potential disparities or societal impacts that may results and b) one asking teams to develop and engaging and informative infographic about a specific healthcare disparity. A sequential mixed-methods pre- and post-semester approach employing quantitative and qualitative methods was used to assess te effectiveness of this curriculum. Results indicate that the entire curriculum had a significant impact on students' knowledge of disparities, the value they place on addressing such disparities, and the role biomedical engineers can play in reducing them.

Background and Motivation

Biomedical engineers (BME) apply engineering principles to solve problems in biology and medicine and have contributed to revolutionary and life-saving outcomes, such as artificial organs, advanced prosthetics, and new pharmaceuticals. As their impact on healthcare and society is significant, how they learn to approach a problem is critical. Given that today's societal challenges are only growing more complex, a new kind of BME is required. Exposing engineering students to non-technical proficiencies such as empathy, ethics, inclusivity, and social justice has been linked to more cutting-edge problem-solving, that incorporates the technical with the social, cultural, economic, political, and historical aspects of those affected by the problem; thereby generating more broadly applicable, accessible, and socially just solutions [1-10].

Despite BME's dramatic impact on individuals and society, the social factors and structures that shape engineering problem-definition and solution processes are mostly unknown to students [11-12]. This may be especially true in the fundamental courses such as cell biology, biomechanics, or physiology, where focus is on covering the core technical material. Because these courses are often required, they have great influence on what BME students come to value as they approach a BME problem [13]. The social dimensions of what is discussed in these classes are always present and just need to be made visible.

Some engineering educators practice technical-social dualism, or the belief that the technical and social aspects of an engineering problem may remain distinct from each other during the design process [16]. This dualism is then transferred to students who use it in their own work. Repeatedly solving engineering problems without the social contexts involved may show

students that these contexts are not important in the practice of engineering [13,16]. Additionally, this persistent socio-technical divide impacts undergraduate retention, especially students historically underrepresented in engineering [17]. And, indeed, students who are more driven by social/humanitarian issues are more likely to be underrepresented in engineering.

A structured curriculum was developed and implemented in a 3rd year BME physiology one-semester, three-credit core course that uses healthcare disparities as a tool to teach students how to integrate social justice into their biomedical problem-solving approaches. This curriculum builds off previous work in this course [18]. As physiology content typically includes medical pathology and diseases, the use of healthcare disparities is a compelling tool for this overall objective.

Disparities in healthcare, or differences in health outcomes between majority and minority populations, are a result of complex sociologic, political, cultural, economic, and health systems factors. These gaps in health outcomes are expected to widen, as those populations most vulnerable to health disparities are among the fastest growing. This crisis needs to be addressed by all stakeholders, including legislators, health professionals, and insurers; but also, other societal entities, such as those who design, build, and administer biomedical and medical technology. Biomedical engineering, by its interdisciplinary nature, is well suited to address such complex challenges. Some effort is being done to incorporate healthcare disparities into biomedical engineering course curricula, but more work is needed in this area [19-21].

Course Design

The structured curriculum reviewed here exposes students to BME-related healthcare disparities (or disparities that arise from a biomedical design or disparities that could be addressed through biomedical design), their causes, and the importance of considering social justice factors like disparities into how we work as biomedical engineers.

The course covers four organ systems: 1) neuro, 2) endocrine, 3) renal, and 4) gastrointestinal. For each system, the class was structured as below:

1. Learn the fundamental physiology for that system
2. Learn what goes physiologically wrong in the pathophysiologies and diseases within that system
3. Learn about healthcare disparities that exist within that system, with a special emphasis on ones that are BME-related.
4. Discuss examples of how physiology knowledge is applied in solving biomedical problems and how researchers have addressed disparities in their work.
5. Complete the discussion questions assignment for that system. This assignment includes questions that force students to dig a little deeper and use external sources of information to find answers. As part of the healthcare disparities structured curriculum, two questions were added to this assignment for each system:
    a. Socially contextualize a decontextualized biomedical problem related to this system
    b. Reflect on the social justice issues that arise in biomedical design within this organ system. What are some of the ways biomedical engineers have addressed these issues in their designs?

In addition to the structure above incorporated for each organ system, students were also asked to complete three stand-alone Equity & Ethics assignments, and two team projects, all discussed below.

Equity & Ethics Assignment #1: Setting the tone

The semester begins with an overview of social justice on the first day of class and its importance in engineering work, followed by a summary of healthcare disparities as a form of social injustice. To help students prepare to participate in discussions around these topics, they were asked to individually reflect on a how a non-inclusive design or healthcare disparity has personally affected them or someone they love for about ten minutes. This introductory ungraded assignment was inspired Nezafati *et al.'s* work integrating an inclusive mindset into BME courses [19]. At this point, the class was then split into small groups of 3-4 (students chose their own groups) and each student was asked to share their experiences, if comfortable doing so. For each experience shared, the group considered whether these experiences may be common for some in our society.

Once groups had shared and reflected on their collective experiences, they were asked to choose one experience and develop a case study aimed at informing and motivating members of the public. The class was provided guidance on writing effective case studies (https://writingcenter.uagc.edu/writing-case-study-analysis and https://www.scu.edu/ethics/focus-areas/technology-ethics/a-template-for-technology-ethics-case-studies/) and given several examples. Groups were then asked to post their case study to the LMS discussion board, and each student in the class was required to read the case studies and comment on others'.

Equity & Ethics Assignment #2: Identifying healthcare disparities as an ethical issue

After the class completed the Neurophysiology module, a class period was dedicated to the discussion of neuroengineering ethics, with a particular focus on the ethics of brain-computer interfaces (BCI). The first team project (discussed below) asks students to propose a design for a BCI and this assignment was developed to aid students in that task. Students were required to read two articles prior to this class period and to write a reflection on what they learned on the LMS discussion board. They were also required to comment on other students' posts. The first paper presented a toolbox of ethical concepts that can be used to analyze issues in neurotechnology [22]. This paper laid out an ethical framework using consequentialism and deontology to recognize ethical issues. The second paper specifically addressed some of the ethical and equitable access issues of BCIs [23].

In class, we reviewed the ethics toolbox presented and talked through a specific example observed in the health center at their university involving the use of EyeGaze technology after a stroke or traumatic brain injury. After this discussion, students broke out into the same teams they are working with on the first team project related to BCIs. Teams were provided six case studies from the Center for Sensorimotor Neural Engineering Case Studies in Neuroethics and asked to choose one to focus on [24]. They were then asked to identify key stakeholder groups and consider their level of autonomy in the decision-making process, and to apply the concepts and principles from the Neuron paper [22] that might help them navigate potential design

approaches while addressing at least three proposed ethical considerations from the Brain Informatics paper [23]. Each team then reported to the class what they had discussed.

In the discussion questions assignment (discussed above) for the Neurophysiology module, students were asked to complete question #8 in the BCI project teams. Question 8 asks students to develop a technical problem statement for their BCI project. For this Equity & Ethics Assignment #2, teams then took what they had learned in the neuroengineering ethics reading and discussion and socially contextualize their technical problem statement and use that new problem statement as their foundation for their proposed design solution (the specifics of the BCI project are discussed below).

The deliverable for this assignment was the new socially contextualized problem statement and a 1-page reflection of the team's discussion and how it informed the changes, as well as what was learned personally as an individual.

Ethics & Equity Assignment #3: Issue of equity in medical device design

After the class completed the Renal Physiology module, a class period was dedicated to the discussion of inequities in medical device design. Prior to this discussion, students were asked to read two articles. The first article presented the challenges associated with medical device regulation and health equity, as well as possible solutions [25]. The second article explores the particular disparities and inequities that exist for a specific medical device with broad use: the pulse oximeter [26]. Students then identified the technological and social problems with this device and the consequences for clinical outcomes, access to care, and impact on caregivers. They then reflected on what other biomedical applications, technologies, or systems might pose the same problems and how these can be addressed. Students posted their reflections in the LMS discussion board and were asked to post on other students' posts as well.

In class, students worked in small groups and discussed each other's posts and their overall response to the articles. They were asked to apply material from the previous papers in neuroengineering ethics, such as principles of biomedical ethics, moral philosophy, and proactive design philosophies. Each team reported a summary of their discussion to the class.

In the discussion questions assignments (discussed above) for the Renal Physiology module, question #8 asked students to write a technical problem statement for a medical device that is used to treat a renal disease/pathology. For this Equity & Ethics Assignment #3, these small groups of students worked on socially contextualizing their technical problem statements. They were also asked to propose adaptations or redesigns of their chosen medical device to make it more equitable.

The final deliverable for this assignment was a 1–2-page summary describing the chosen renal medical device and how their adaptations address considerations of equitable access, including cost, availability, and potential scalability. This summary also included both problem statements and a reflection of what was learned from this assignment.

Team Project #1: Brain-Computer Interface Design:
Student teams were asked to propose a brain-computer interface design to help a patient regain a lost sense. This project is assigned after completing the neurophysiology module and the neuroengineering ethics discussion. In previous semesters, teams were asked to create a 7-minute presentation introducing their team's design idea that includes a summary of the background physiology knowledge needed to understand the proposal, a summary of what's been done before in this area, a summary of the gaps in knowledge or technology that still exists and how their proposed solution addresses that, and at least three specific aims that would need to be proven to show their design works.

For this new structured curriculum on healthcare disparities, teams were additionally required to socially contextualize their technical problem statement and summarize any disparities and societal impacts that may result from their design. The latter was prompted with the following questions: 1) What concepts and principles from the neuroengineering ethics discussion did you use to help you navigate potential design approaches; 2) How will you ensure your design will be made available to all people equitably as much as possible; 3) How will you keep costs under control; and 4) How might you alter the design to make it more affordable for use in resource-starved areas of the world.

Team Project #2: Healthcare Disparity Infographic:
This project has mostly stayed the same as was presented previously [18]. For this project, teams are asked to create an informative and engaging infographic about a particular BME-related healthcare disparity. The infographic must describe the disparity, the populations affected and how, the current outcomes of that disparity, what role BMEs play in contributing to the disparity, and how can BMEs work to eliminate the disparity. Teams print and present their infographics publicly in a showcase, and the BME community and its clinical partners are invited.

Research Methodology
The overall goals of this study are a) to understand how the inclusion of this structured healthcare disparities curriculum affects student awareness of these social injustices, b) biomedical engineers' role in addressing them, and c) the value students place on addressing disparities and social injustices in their own design work. The below research questions were therefore assessed:

1. What effect, if any, does the healthcare disparities curriculum have on students' awareness of these issues?

2. What effect, if any, does the healthcare disparities curriculum have on student perception of the role of biomedical engineers in addressing them?

3. What effect, if any, does the healthcare disparities curriculum have on the value students place on social justice issues like healthcare disparities?

4. What effect, if any, does the healthcare disparities curriculum have on student beliefs that they can integrate social justice issues like healthcare disparities into their biomedical engineering work?

This study took place in the Fall 2024 semester at a major R1 university under IRB approval (protocol #6835). A sequential mixed-methods approach was used, employing quantitative methods in the form of pre- and post-semester surveys. In both surveys, 25 five-point Likert-scale questions were asked, ten aimed at understanding what factors participants think are important when approaching a BME problem and three aimed at gauging their familiarity with and ability to integrate social justice issues into BME. A matrix of the remaining 12 questions was developed using a modified version of two well-validated tools: the Social Justice Perspective Survey designed to measure beliefs about the role of engineers in society and the Engineering Social Justice Scale designed to assess students' attitudes and beliefs around social justice in engineering [27-28].

In the post-semester survey, some additional quantitative and qualitative questions were included to assess student impressions of the course curriculum.

Data Analysis:

Participants included 67 out of 72 students (93%) who completed both the pre- and/or post-semester surveys. Likert scale quantitative survey data collected from the paired pre/post-semester survey questions were analyzed for changes between answers at the beginning and end of the new curriculum. Unpaired post-semester survey questions were assessed independently. For the open-ended qualitative data, a general inductive content analysis approach was employed. The entire data set was iteratively coded and analyzed for emergent themes.

Results:

Factors students value when approaching a biomedical engineering problem

On both the pre- and post-semester surveys, students were asked to rate the importance of several factors when approaching a BME problem, using a Likert scale with the following choices: Extremely Important, Very Important, Moderately Important, Slightly Important, and Not Important At All. The factors included a) technical specifications, b) the needs of the users or target population, c) empathy, d) cultural awareness/sensitivity, e) the ethics surrounding the problem and solutions, f) working in diverse teams, and g) acknowledging and addressing current and potential related disparities. This set of questions addressed research questions 2 & 3.

Students entered the semester with an already well-developed view of the value of non-technical factors in approaching engineering problems, with 73-95% of students rating these factors as Extremely or Very Important, but this range had changed to 90-100% at the end of the semester [Appendix Figures 1 and Figure 1]. An increase from pre- to post-semester was observed for each factor. Working in diverse teams had the largest increase from the pre-semester survey (17 percentage-points), followed by acknowledging and addressing current and potential disparities (12 percentage points) and cultural awareness/sensitivity (10 percentage points). These specific factors also had the lowest percentage of students rating them as Extremely or Very Important at the beginning of the semester (73%, 86%, and 82%, respectively). The smallest increases from pre- to post-semester were seen for the ethics surrounding the problem and solutions (4 percentage points), technical specifications (5 percentage points) and the needs of the users or target population (5 percentage points). These factors were already rated as Extremely or Very Important by a large percentage of students (92%, 89%, and 95%, respectively).

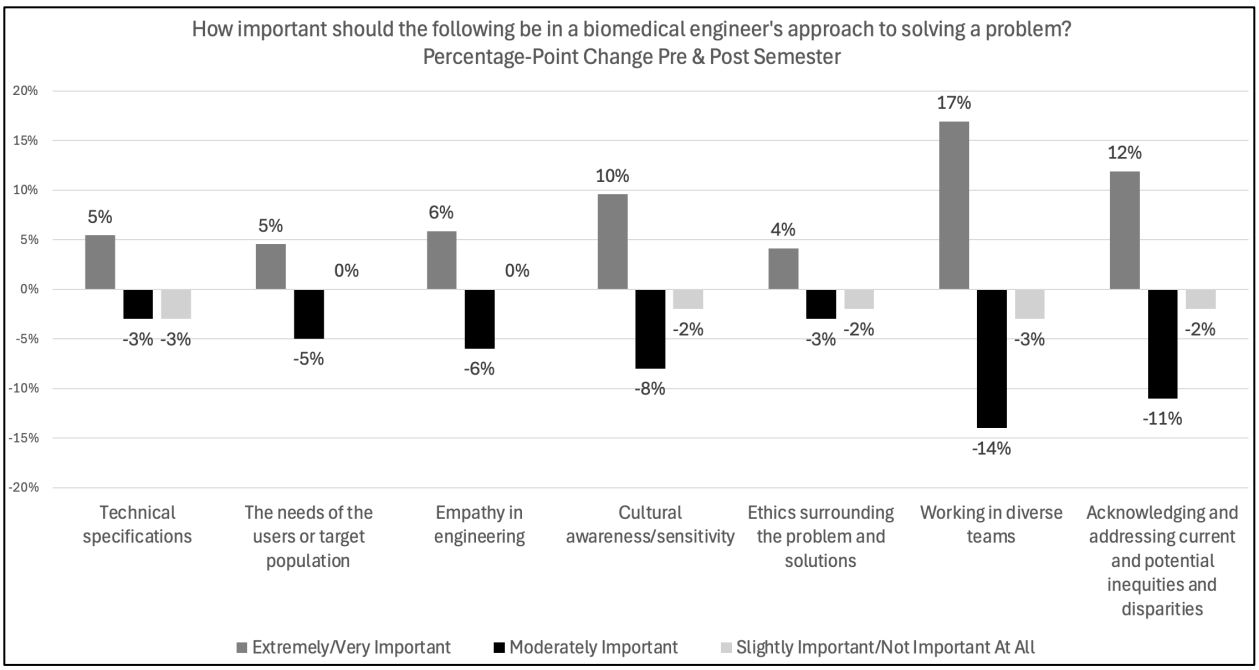

Figure 1: Rating the value placed on different factors when approaching a biomedical problem – percentage point change from pre- to post-semester

Both surveys also asked students to rate the value they place on addressing social justice issues as a future BME, using the following Likert scale: Very High Value, Somewhat High Value, Average Value, Somewhat Low Value, Very Low Value. This question addresses research question 3. At the beginning of the semester, 42% responded with the Very High Value option, and this percentage increased to 67% at the end of the semester [Figure 2]. Additionally, 7% of students chose Somewhat Low Value or Very Low Value on the pre-semester survey, but only 2% chose these options on the post-semester one.

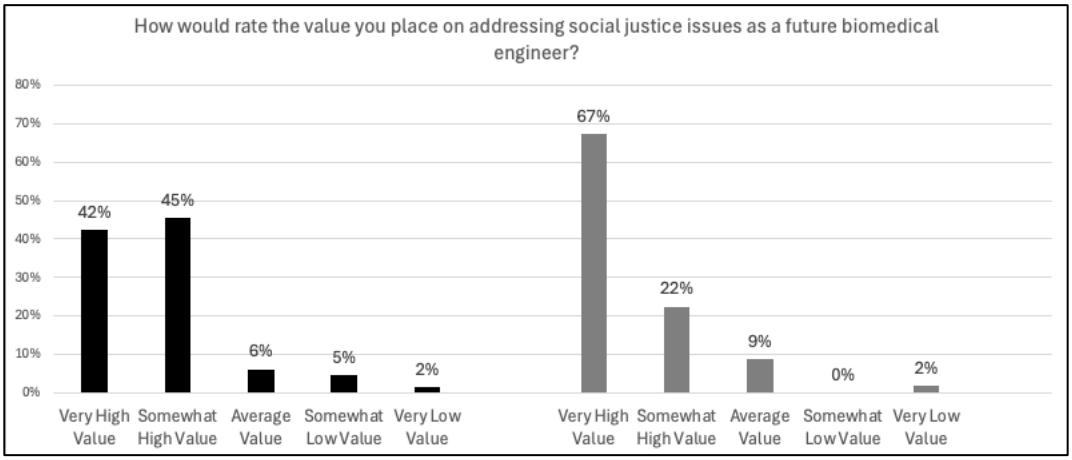

Figure 2: Pre- and post-semester responses rating the value placed on addressing social justice issues

Student familiarity with social just health issues

Next, students were asked to rate their familiarity with three topics: 1) the concept of social justice in engineering design, 2) healthcare disparities and their impact, and 3) the ways BMEs can address social justice issues. Students were asked to rate their familiarity using a Likert-

Scale with the following range: Extremely Familiar, Very Familiar, Moderately Familiar, Slightly Familiar, and Not Familiar At All. This set of questions addressed research questions 1, 2, and 3.

Between 31-40% of students indicated they were Extremely or Very Familiar with these topics at the beginning of the semester, and this range increased to between 75-93% by the end of the semester [Appendix Figure 2 & Figure 3]. The largest improvements in students feeling Extremely or Very Familiar was observed for the last two topics (healthcare disparities & their impact, and the ways BMEs can address social justice issues), with a 53- and 54 percentage point increase, respectively. Students who felt Extremely or Very Familiar with the first topic (concept of social justice in engineering design) increased from 37% pre-semester to 75% post-semester (38% increase).

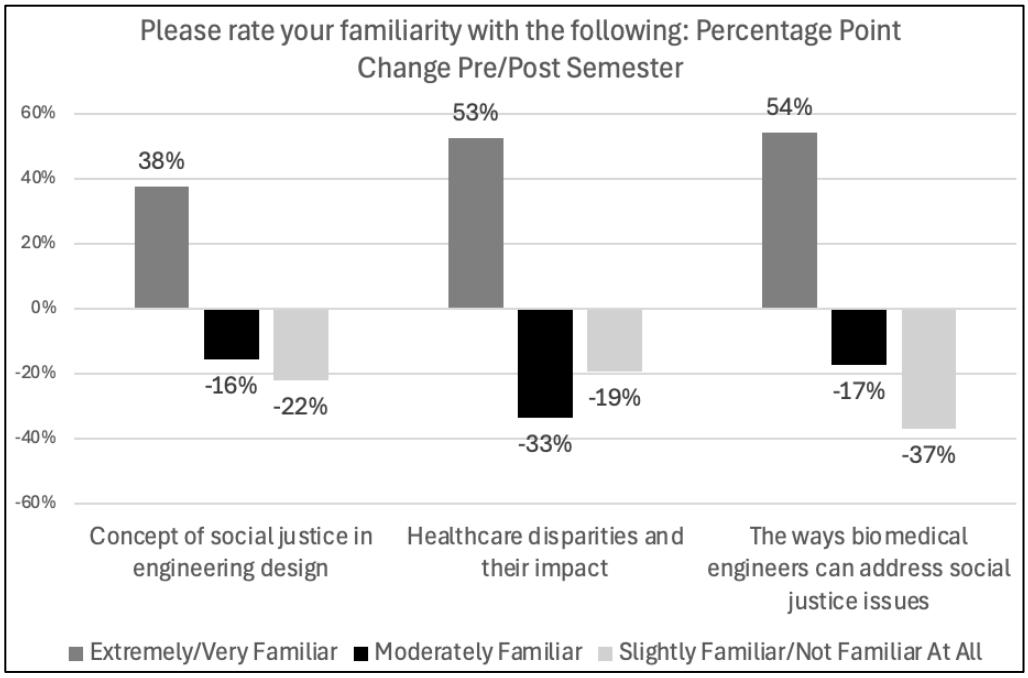

Figure 3: Rating familiarity with social justice topics – percentage point change from pre- to post-semester

Both surveys also included a question asking students to rate their ability to integrate social justice issues into their own BME work using the following Likert scale options: Excellent, Good, Average, Poor, and Terrible. This question addressed research question 4. This question addressed research questions #4. At the beginning of the semester, 12% and 48% chose Excellent and Good, respectively, while these same percentages increased to 29% and 60% on the post-semester survey [Figure 4]. Students choosing the Average response decreased from 36% to 9%, while those choosing Poor or Terrible responses decreased slightly from 4% to 2%.

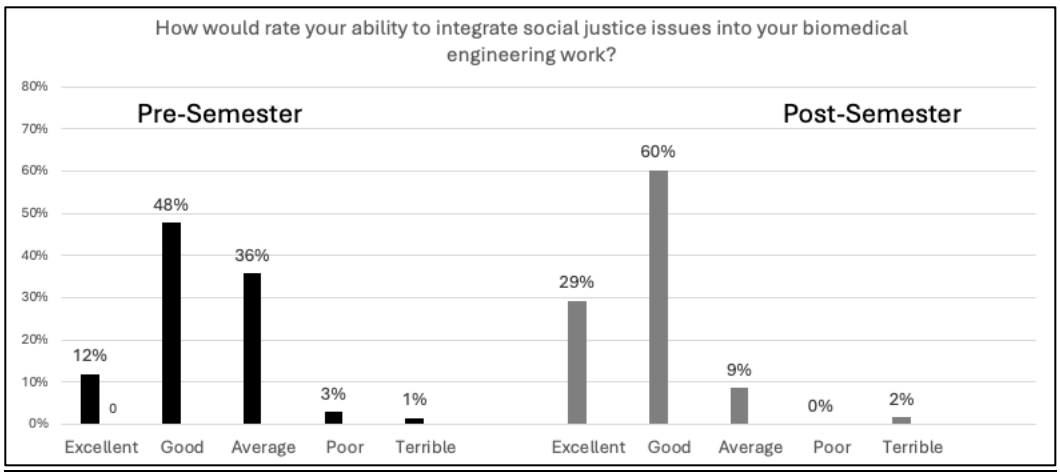

Figure 4: Pre- and post-semester responses rating students' ability to address social justice issues

Student belief and attitudes around social justice in biomedical engineering

A modified version of the Social Justice Perspective Survey and the Engineering Social Justice Scale was then used to assess students' attitudes and beliefs around social justice in engineering [27-28]. For both the pre- and post-semester surveys, students were given a series of 12 statements and asked to rate their level of agreement using the following Likert scale options, each assigned a numerical value between 1-5: Very Strong (5), Somewhat Strong (4), Neutral (3), Somewhat Weak (2), Very Weak (1). Two exceptions to these numerical value assignments exist for the first two questions, in which case the scale was reversed: Very Strong was assigned the value of 1 and Very Weak was assigned the value of 5. An average numerical score was calculated for each statement for both the pre-semester and post-semester surveys. This set of questions addressed research questions 2 and 3, predominately.

Increases in the average numerical score for each of the statements from pre- to post-semester were observed, except for those related to the environment or sustainability (statements 6, 8 and 12), which were not directly covered in this course [Figure 5]. The largest increases in scores were observed for statements 2 (increased from 3.30 to 3.62) and 3 (increased from 3.52 to 3.76). *Note: statement 2 had a reversed numerical value assignment compared to statement 3.* All other statements (except for 6, 8, and 12) saw increases ranging from just 0.02 to 0.12.

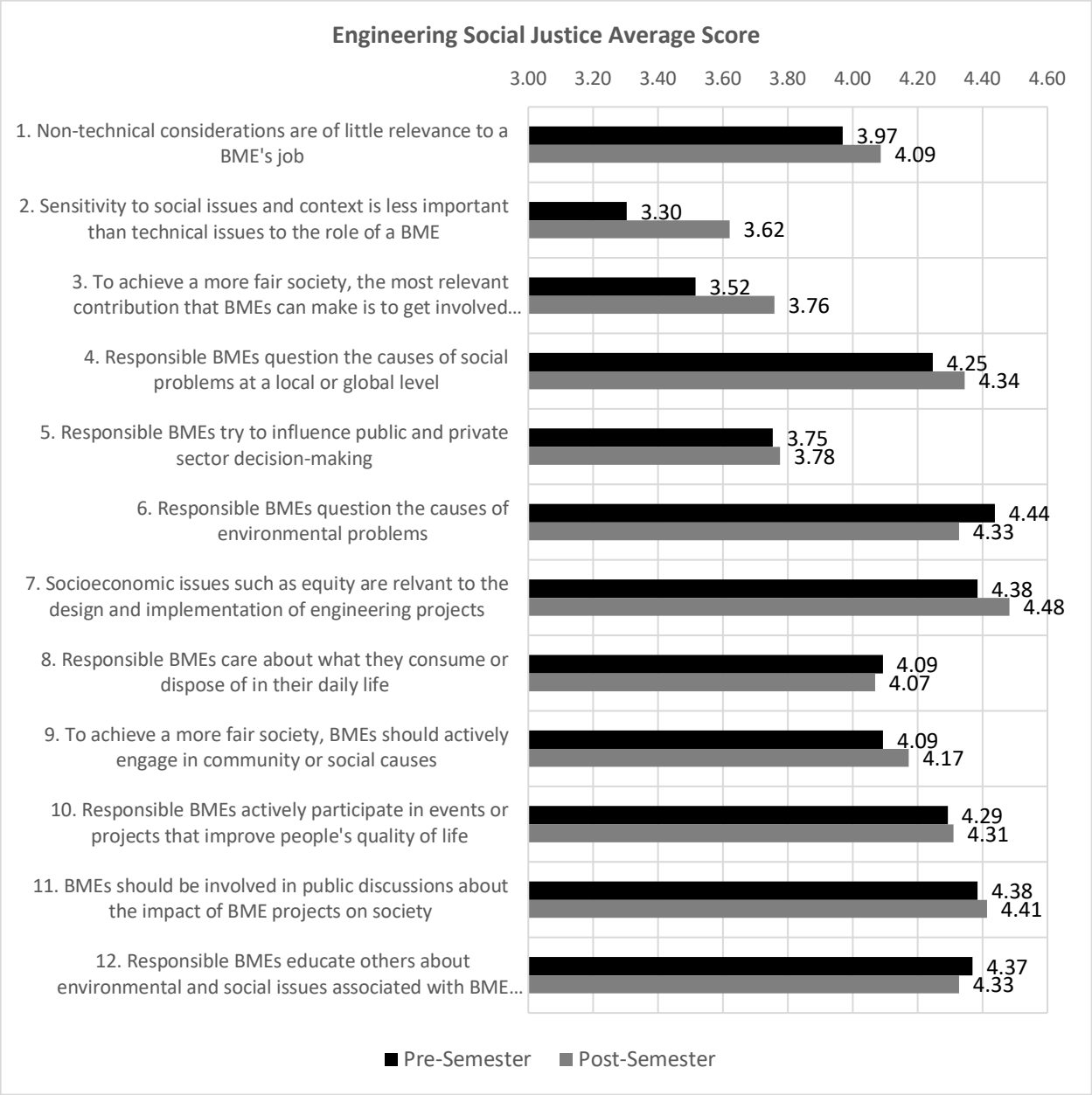

Figure 5: Engineering Social Justice Average Numerical Score. Note: x-axis shows from 3.00-4.60 of total scale

<u>Students' overall opinions of the healthcare disparities curriculum</u>

Finally, a separate set of questions were added to the post-semester survey only to assess students' overall impression of the healthcare disparities curriculum. A large majority (88%) found the curriculum to be Extremely or Very Effective [Figure 6], while 10% found it to be Moderately Effective, and 2% found it to be Slightly Effective. No participant found it to be Not Effective At All.

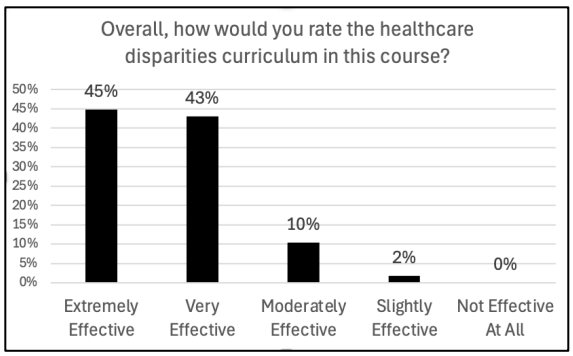

Figure 6: Overall effectiveness of healthcare disparities curriculum

In order to understand how students view individual components of the curriculum, they were asked how well each component did the following: 1) increased their awareness of social justice issues like healthcare disparities, 2) increased their awareness of the role BMEs play in addressing social justice issues, 3) increased the value they place on integrating social justice issues into biomedical problem-solving, and 4) increased their ability to integrate social justice issues into their own BME work. The individual components assessed were the healthcare disparities Case Studies assignment, Class Discussions of disparities, the Neuroengineering Ethics assignment, the BCI team project, the Healthcare Disparities Infographic team project, and the Medical Devices Inequities assignment. Students could choose a response from the following Likert scale for each curricular component for all four topics: Very Well, Somewhat Well, Neutral, Somewhat Poorly, Very Poorly.

A table of all responses can be found in the Appendix [Appendix Table 1]. Figure 7 shows the percentage of students who chose Very Well or Somewhat Well for each curricular component for all four topics. Between 86-97% students felt that the individual curricular components helped to increase awareness of social justice issues either very or somewhat well. The most effective component for this topic was the healthcare disparities infographic team project (97%), followed by the case studies (93%). Between 88-97% students felt that the individual curricular components helped increase awareness of the role BMEs play in addressing social justice issues. The most effective component for this topic was the BCI team project (97%), followed by the healthcare disparities infographic team project (96%) and the medical device inequities assignment (93%).

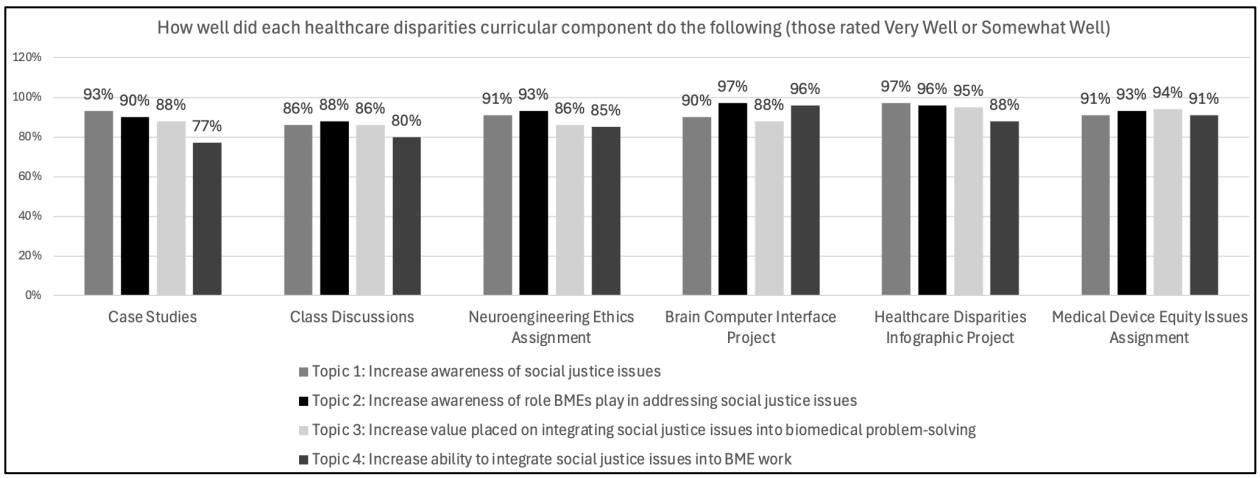

Figure 7: Effectiveness of each curricular component

For increasing the value students place on integrating social justice issues into biomedical problem solving, between 86-95% of students felt the individual curricular components were very or somewhat effective. The most effective component for this topic was again the healthcare disparities infographic team project (95%), followed by the medical device inequities assignment (94%). And finally, between 77-96% of students felt the individual curricular components were very or somewhat effective at increasing their ability to integrate social justice issues into their own BME work. The most effective components here was the BCI team project (96%).

Overall, the healthcare disparity infographic team project covered all four topics the most effectively (average of 94% for all four), followed by the BCI team project (93%) and the medical devices inequity assignment (93%). The class discussions had the lowest overall average effect (85%).

The post-semester survey ended with the two following open-ended questions:

1. Overall, what did you like about the healthcare disparities curriculum and why?
2. Please describe any improvements the instructor could make in covering healthcare disparities in this course.

Inductive coding was used to measure themes in the 67 responses. As shown in Table 1, the top three reasons students liked that the curriculum was that it increased awareness of disparities in general, it integrated social justice issues into physiology content, and it taught them the importance of valuing social justice specifically as a BME. Some examples of responses to this question are listed below:

> *"I liked that this was incorporated into a technical engineering course and not just talked about separately in an STS course."*

> *"I enjoyed the fact that the healthcare disparity assignments allowed us a change to apply the physiology knowledge we are learning in class to real life scenarios."*

"I really liked that it allowed me to do my own research in the disparities but opened my eyes to how important it is to consider social, cultural, and other aspects in the engineering process!"

"I liked how relevant disparities would be brought up after each lecture to really help tie it in to the material and help me understand how it was relevant to me as a BME."

"It was eye-opening. It integrated very well with the rest of the course and I feel like I learned a lot."

Table 1 - Responses to: What did you like about the healthcare disparities curriculum and why?

Inductive Coding Theme	Number of respondents
Increased awareness of disparities overall	16
Integration of social justice issues into the physiology content	13
Realization of the importance of valuing social justice specifically as a BME	12
The application to real-life scenarios	10
Learning about a topic not taught in other courses	9
Assignments allowed for deeper self-directed learning about disparities	8
It was integrated throughout the semester instead of one or two sessions	7
Generally interesting to learn about	4
Break from the technical content of the course	1

A large majority of respondents to question 2 felt no improvements to the curriculum were needed, while a few felt the assignments could be repetitive or that case studies could have been more patient-specific [Table 2]. Some examples of responses to this question are listed below:

"I think the instructor really helped me to understand healthcare disparities."

"It sometimes felt repetitive and surface; help us find more insightful and 'hidden' disparities."

"Integrate information on disparities throughout physiology lecture vs the end."

Table 2 - Responses to: Please describe any improvements the instructor could make in covering healthcare disparities in this course

Inductive Coding Theme	Number of respondents
None	22
Assignments sometimes felt repetitive	4
Need more patient-specific case studies to discuss	2
Need a discussion on how to improve costs in healthcare	1
I didn't connect with any of the disparities	1
Bring in guest speakers	1

Discussion

Core engineering courses can serve as strategic opportunities to introduce social content related to the technical topics being discussed. These sociotechnical dimensions are often already present and simply need to be explicitly addressed and reviewed. Incorporating such dimensions as ethics, empathy, equity, and inclusivity is vitally important in training a workforce of

biomedical and medical scientists and engineers in the generation of health products and solutions that serve all populations.

Previous studies have shown the educational benefits of working on socially-minded engineering projects, such as increased retention, especially for women and minoritized students [29-34]. And indeed, more students are becoming committed to projects with social impact, with 72% expressing interest in future careers that prioritize sociotechnical solutions [35-36].

This paper presents a structure curriculum developed for a 3rd year BME physiology core course that centers healthcare disparities as a tool integrate social justice issues into discussions on physiology concepts. Healthcare disparities were the focus here as physiology class content typically includes medical pathophysiology discussions, and these disparities are strong examples of inequities that can be addressed by future biomedical engineers and physicians.

The healthcare disparities curriculum increased student's awareness of social justice issues

When participants were asked to rate their familiarity with three topics, the number of responders choosing Extremely or Very Familiar increased for all three from the beginning to the end of the semester: 1) the concept of social justice in engineering design (37 percentage point increase), 2) healthcare disparities and their impacts (53 percentage point increase), and 3) the ways BME cans address social justice issues in their work (54 percentage point increase) [Figure 3]. The total percentage of participants who responded Extremely or Very Familiar was 75%, 93%, and 86%, respectively.

All individual curricular components may have attributed to these increases, with between 86-97% of post-semester survey participants choosing Very or Somewhat Well when rating the effectiveness of each at increasing their awareness of social justice issues [Figure 7]. The healthcare disparities infographic assignment was the top performer at 97%. This assignment asked student teams to do some self-directed learning about a particular healthcare disparity of their choice and dig deeper into its impact. Additionally, teams were asked to create engaging and informative infographics, which were printed and on display for the entire class to see. This showcase facilitated a great deal of discussion and energy, as well as peer learning.

The case study assignment was also quite effective at increasing social justice issues awareness, with 93% of participants rating it as Very or Somewhat Well. Here, students were asked to discuss healthcare disparities that have affected them or someone they love in small groups, choose one, and write a case study for the rest of the class to read and comment on using the online discussion board. This assignment prompted small group and class-wide discussions about the variety of disparities that can affect people with different lived experiences. The discussion board posts for this assignment were quite lively, and the students were very engaged and respectful in their interactions.

Finally, the top coded categories of answers to the survey question about what students liked most about the course was an increased awareness of disparities overall and how the disparities curriculum was integrated into the physiology content and its application to real-life scenarios [Table 1].

The healthcare disparities curriculum increased the value students place on social justice issues and the role BMEs play in addressing them

When participants were asked to rate the importance of different factors when approaching a BME problem, increases were seen for each factor from pre- to post-semester surveys for those choosing the Extremely or Very Important options [Figure 1]. The largest increases were seen for Working in diverse teams (17 percentage point increase, Acknowledging and addressing potential disparities (12 percentage point increase), and Multicultural awareness (10 percentage point increase). The range for all factors on the post-semester survey for Extremely or Very Important was 91-100%, with Needs of users and target populations (100%), Empathy in engineering (98%), and Acknowledging and addressing potential disparities (98%) being the highest, and Working in diverse teams (90%) and Multicultural Awareness (91%) being the lowest.

A 25 percentage point increase was also observed for participants who rated the value of addressing social justice issues as future BMEs as Very High (or an increase from 42% pre-semester to 67% post-semester) [Figure 2]. This increase in value was also observed using the modified Social Justice Perspective Survey and Engineering Social Justice Scale, which asked participants to rate their agreement with a series of 12 statements [Figure 5]. The Likert-scale responses were then numerically coded and scores averaged. Across the 12 statements, the overall score increased from 4.07 pre-semester to 4.14 post-semester (0.07 increase). Average scores increased for each of the 12 statements, but the larger increases could be seen, in order of increase size, for statement #2 (Sensitivity to social issues and context is less important than technical issues to the role of BMEs—these responses were reverse coded), statement #3 (To achieve a more fair society, the most relevant contribution that BMEs can make is to get involved publicly in the analysis and discussions about social, political, and economic structures, and statement #4 (Non-technical considerations are of little relevance to a BME's job—these responses were reverse coded).

These gains in the value students place of integrating social justice issues into BME problem solving may be contributed to several components of the disparities curriculum. When participants were asked to rate the effectiveness of these components at increasing their awareness of the role BMEs play in addressing social justice issues, all were effective, with between 88-97% of respondents choosing Very or Somewhat Well [Figure 7]. However, the most effective were the two team projects: the healthcare disparities infographic, as discussed above, and the brain computer interface project. The percentage of respondents rating these components as Very or Somewhat Well were 96% and 97%, respectively. The brain computer interface assignment tasked student teams with proposing a design for a BCI that can help a patient regain a lost sense. Teams were asked to specifically consider issues of access and equity in their background research and proposed design. The fact that this assignment allowed students to practice integrating social justice issues into a BME problem may have led to the positive increases observed in the awareness of the role BMEs play in doing so.

When participants were asked which curricular components most increased the value they place on integrating social justice issues into BME problem solving, again all components were effective (between 86-95% choosing Very or Somewhat Well). And again, the healthcare disparities infographic project was top, with 95% choosing Very or Somewhat Well, followed by

the medical device equity assignment (95% choosing Very or Somewhat Well). The later assignment asked students to work in teams to propose a redesign of a renal medical device to make it more equitable and accessible. Like with the BCI project, students again had the opportunity to practice integrating social justice issues into a BME problem, which may have led to the positive increased seen in the value they place on doing so.

Finally, the 3rd largest category of answer to the survey question about what students liked most about the course was Realizing the importance of valuing social justice specifically in the BME discipline [Table 1].

The healthcare disparities curriculum increased student confidence in their ability to integrate social justice issues into their own BME work

When participants were asked to rate their ability to integrate social justice issues into their own BME work, a 17 percentage point increase was observed for the Excellent and Good response options from the pre- to the post-semester responses [Figure 4]. At the end of the semester, 89% felt they had an Excellent ability to integrate these issues.

Again, all individual curricular components were effective at increasing the ability of participants to integrate these issues, with between 77-96% responding Very or Somewhat Well [Figure 7]. The BCI project was the clear stand out here with 96% responding Very or Somewhat Well. Again, this project allows students to practice doing exactly this, as does the Medical Device Equity assignment, which was the 2nd most effective at 91%.

Limitations

All analyses were conducted using survey responses, many of which relied on Likert scale questions. These scales are useful in evaluating participants' self-concept and confidence but are limited in measuring actual skill development. Future work will utilize more scenario-based assessment techniques, assignment deliverables, and assignment reflection overviews.

Lessons Learned

The primary lesson learned while incorporating this healthcare disparities curriculum into a physiology class was that students are thirsty for this knowledge and are very appreciative of learning what to them is a critical topic that should be learned in more engineering courses. Student remained highly engaged throughout the entire semester and routinely came to be expressing gratitude. It was an absolute pleasure to introduce a social justice issues topic, sit back, and watch the class blossom into meaningful and constructive discussions.

Additionally, when attempting to weave social justice issues, or any other socially-focused topics, into a technical course, it is key to use the technical content as a base. By consistently utilizing the physiology and pathophysiology concepts and mechanisms, as well as real-life BME design problems and solutions, to introduce various disparities, students were able to see the thread of issues like social justice, empathy, and ethics, that exists across the discipline. This integration also allows one to reach more students, especially those who may initially think that learning about non-technical factors should not be a priority.

Finally, the course online discussion board was used in all three of the Ethics & Equity assignments. And although a small minority of students felt this was somewhat repetitive, overall this tool is a powerful one. The out-of-class online format allowed a larger number of students in the class to actively participate. It also gave students time to reflect, come back to the discussion, and engage further. Finally, the online discussion format was highly conducive to peer learning. Students really bounced off each other's ideas and findings

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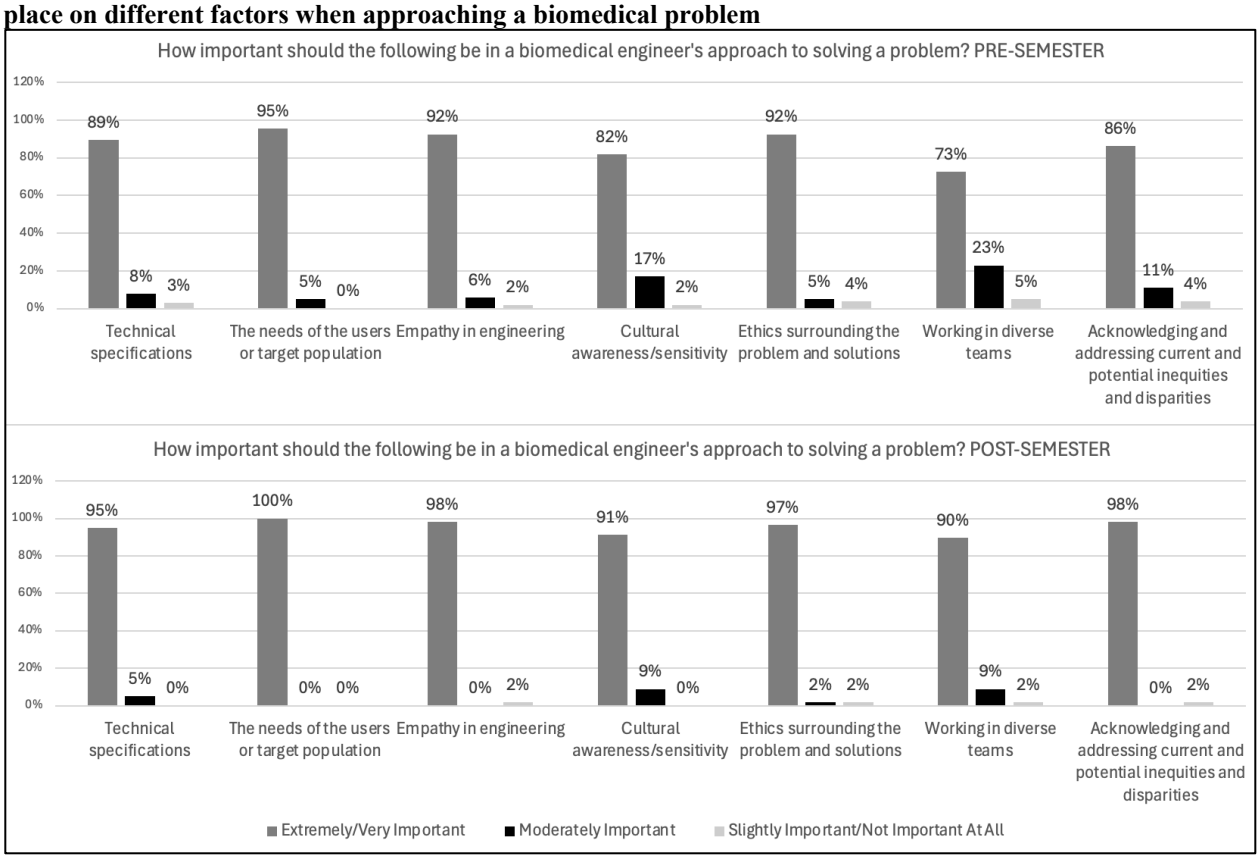
Appendix

Appendix Figure 1: Pre- and post-semester survey responses when students were ask to rate the value they place on different factors when approaching a biomedical problem



Appendix Figure 2: Pre- and post-semester survey responses when students were asked to rate their familiarity with social justice topics.

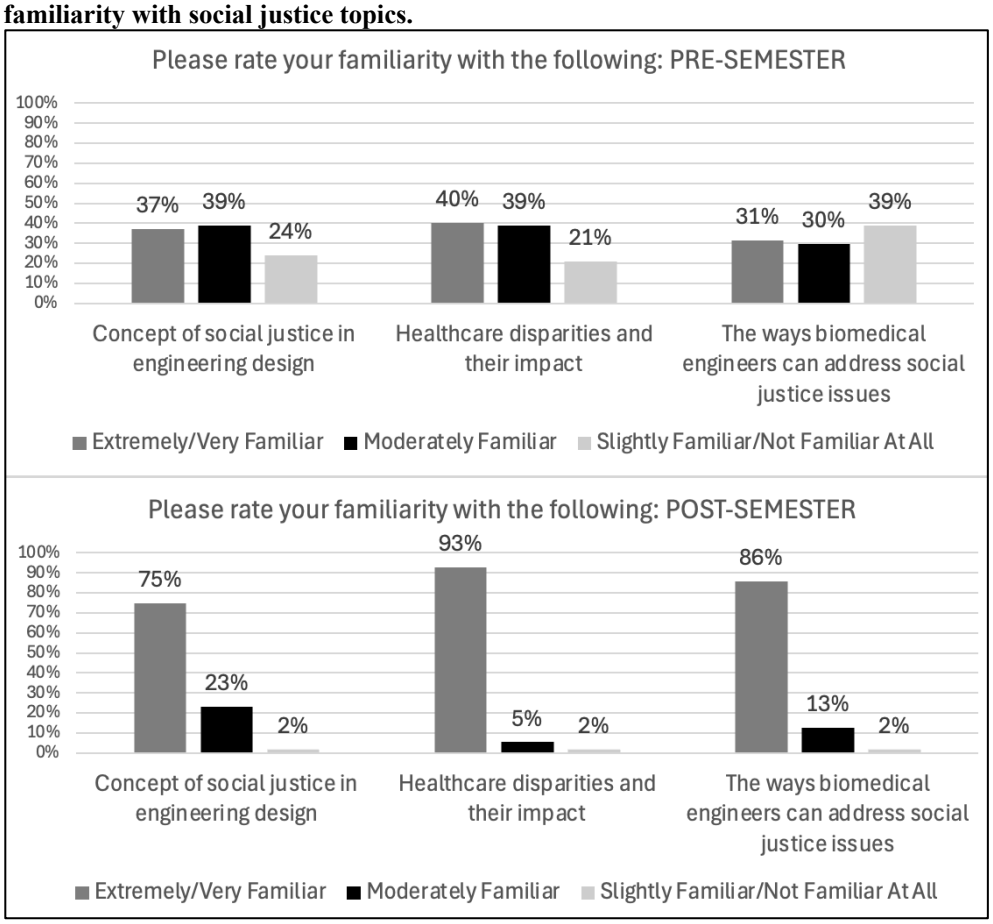


Table 2:

Question	Curricular Component	Very Well	Somewhat Well	Neutral	Somewhat Poorly	Very Poorly
Increased your awareness of social justice issues like healthcare disparities	Case Studies Assignment	53%	40%	5%	2%	0%
	Class Discussions	43%	43%	9%	5%	0%
	Neuroengineering Ethics Assignment	50%	41%	7%	2%	0%
	Brain Computer Interface Team Project	47%	43%	9%	2%	0%
	Healthcare Disparities Infographic Team Project	66%	31%	3%	0%	0%
	Medical Devices Equity Assignment	41%	50%	7%	2%	0%
Increased your awareness of the role BMEs play in addressing social justice issues	Case Studies Assignment	43%	47%	7%	3%	0%
	Class Discussions	43%	45%	10%	2%	0%
	Neuroengineering Ethics Assignment	53%	40%	7%	0%	0%
	Brain Computer Interface Team Project	50%	47%	3%	0%	0%
	Healthcare Disparities Infographic Team Project	62%	34%	2%	2%	0%
	Medical Devices Equity Assignment	55%	38%	3%	0%	0%
Increased the value you place on integrating social justice issues into your biomedical problem-solving	Case Studies Assignment	47%	41%	9%	2%	2%
	Class Discussions	41%	45%	12%	2%	0%
	Neuroengineering Ethics Assignment	55%	31%	12%	2%	0%
	Brain Computer Interface Team Project	59%	29%	10%	2%	0%
	Healthcare Disparities Infographic Team Project	64%	31%	5%	0%	0%
	Medical Devices Equity Assignment	60%	34%	5%	0%	0%
Increased your ability to integrate social justice issues into your BME work	Case Studies Assignment	43%	34%	17%	5%	0%
	Class Discussions	33%	47%	19%	2%	0%
	Neuroengineering Ethics Assignment	45%	40%	10%	5%	0%
	Brain Computer Interface Team Project	48%	48%	2%	2%	0%
	Healthcare Disparities Infographic Team Project	48%	40%	10%	2%	0%

	Medical Devices Equity Assignment	48%	43%	7%	2%	0%