Education of Healthcare Disparities: Creating a Framework for Worcester Polytechnic Institute's Biomedical Engineering Department

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ABSTRACT:

Biomedical engineering (BME) students must recognize their need to identify and prevent disparities in healthcare in their future careers, as their profession directly impacts the field of healthcare. Yet, the undergraduate BME curriculum is currently lacking a standardized healthcare disparities content. The purpose of this project was to develop a healthcare disparities curriculum spanning all four grade levels and examine its effectiveness when piloted at each course level in the BME department at Worcester Polytechnic Institute. Bloomberg's Taxonomy of Knowledge was utilized as a scaffold to create educational healthcare disparities with specific learning outcomes for each course level. We found our curriculum was successful in enhancing students' knowledge of healthcare disparities and should be considered as a permanent solution to standardization of healthcare disparities education.

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EXECUTIVE SUMMARY

Introduction: Undergraduate biomedical engineering curriculum is currently lacking a standardized healthcare disparities education. Based on the findings from this study, there is a stark gap in knowledge of healthcare disparities in the undergraduate BME curriculum that both students and professors recognize and desire to be addressed. Biomedical engineers must be educated on the topic of healthcare disparities in order to recognize and prevent them in their future careers. The purpose of this study was to develop a hierarchical healthcare disparities curriculum and examine its effectiveness when piloted to each course level in the BME department.

Methods: Our group developed healthcare disparities modules for each course level in the BME department with course level appropriate content, such as definitions and case studies, based on the scaffolding of Bloombergberg's Taxonomy of Knowledge. We surveyed BME professors prior to delivery of our modules in order to establish the faculty climate surrounding the importance of healthcare disparity education. Additionally, interviewed BME professors and conducted research on existing literature to develop the modules. Our group developed a pre-survey and post-surveys for each course level in order to analyze the effectiveness of our modules and the desire for a healthcare disparities education in the BME department. Based on results, our group proposed future recommendations for such a comprehensive curriculum to be established for the BME department.

Results: The results displayed BME professors and students believe a healthcare disparities education is important; however, it is currently lacking at WPI. It was reported that 44.8% of

BME students (n = 165) had not received any healthcare disparity education in their BME courses at WPI, despite a mean rating of 4.52, correlating with a rating of “very important” when asked if they believed it is important to address healthcare disparities in their future careers. Additionally, students across all grade levels indicated a mean score of 2.24 when asked if they had any previous knowledge on healthcare disparities, corresponding with a “moderate amount” of knowledge. After delivery of the modules, it was found the modules improved the students' knowledge on healthcare disparities. The survey results showed the majority of students indicated “definitely yes” when asked if the module helped them to improve their knowledge of healthcare disparities.

Conclusion: Our findings demonstrated a healthcare disparity curriculum delivered to students through modules is an effective method to educate students on the topic of healthcare disparities. The healthcare disparity curriculum developed in this IQP can be used as a guide to develop a permanent solution to standardization of healthcare disparities education within the BME department at WPI.

I. Introduction

Health disparities are preventable differences in outcomes related to health including disease, injury, or opportunities among certain populations (Health Disparities | DASH | CDC, 2022). In the United States, there are currently social structures including goods, services, and societal attention that contribute to the ongoing dilemma of health disparities (National Academies of Sciences et al., 2017). Healthcare disparities are a leading contributor to current trends in health disparities as they lead to differences in access, availability, and quality of medical care within populations (Disparities, 2021). Healthcare disparities (HCD) remain a crisis and dilemma globally with almost half of the world population reported not having access to basic health services in 2017 (Tracking Universal Health Coverage, 2017).

In the United States specifically, there exist stark disparities in healthcare outcomes for certain populations, including major racial disparities in health outcomes. One such example is Black individuals have the highest mortality rate for all cancers combined in comparison to all other ethic counterparts (Carratala et al., 2020). Initiatives have been called to action in the United States in an attempt to combat such health disparities. One major example is the National Institute on Minority Health and Health Disparities (NIH) Strategic Plan 2021-2025 – a five-year strategic plan to address health disparities. While initiatives to eliminate health disparities have taken place on a broader scale, possible health disparities can stem from specific disciplines like engineering. The work of engineers can contribute to this cause through mitigating healthcare disparities, which in turn would help to address health disparities. Engineers can make considerations during design processes about who can access their products, who can afford their products, and whether everyone can benefit from them in order to help mitigate and prevent

HCD. Such considerations require the engineer to be informed about HCD to allow them to be able to recognize when a potential HCD could occur and to prevent them from happening.

While HCD can be combated by exposing and educating engineers about them, there is currently a lack of education about addressing healthcare disparities education and implementation in undergraduate curricula (Wasserman, 2019). Biomedical engineering (BME) is an engineering profession that directly interacts with and impacts the field of healthcare, and as such, students pursing degrees in biomedical engineering should be educated on the topic of HCD in order to help prevent them (Wasserman, 2019). While there is literature on trials to incorporate education on HCD in BME undergraduate curriculums, there is a gap in literature investigating sustainable methods to implement a comprehensive curriculum across a BME department. Multiple institutions have incorporated standalone courses to address ethics and HCD curricula (Vazquez 2018 & Nezafati 2021); however, this approach does not work for every institution, as it is often difficult to add a required course to an existing curriculum.

Worcester Polytechnic Institute is a technical institution that offers BME as an undergraduate degree. The Accreditation Board for Engineering and Technology (ABET) reviews engineering programs to ensure standards are met to produce "graduates prepared to enter a global workforce" (*About ABET | ABET*, 2021). ABET requires programs meet ethical standards. The current ABET requirements relating to ethics under the ABET 2021-2022 Outcomes Criterion (I3) states students must have:

> *(2) 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.*

(4) an ability to recognize ethical and professional responsibilities in engineering situations and made informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts (*Criteria for Accrediting Engineering Programs, 2021 – 2022 | ABET*, 2022)

While ABET states students must be able to meet these standards, the BME department at WPI currently lacks a standardized healthcare disparity curriculum, and as such, students might not be receiving the education they need to enter the global workforce. Previous Interactive Disciplinary Projects (IQP) have established the need and desire for such a curriculum within the BME department and have attempted to implement one. These projects concluded education across the curriculum rather than through a standalone course is the best mode of delivery; however, such IQPs have been unsuccessful in developing a sustainable and required curriculum (Cordner et al., 2021 & Jackson et al., 2015). The need for a comprehensive curriculum to be established by the BME curriculum is unmet.

Mode of delivery is a factor to consider while creating a long-term structure. In-person discussions have been shown to be one of the most efficient educational techniques (Ningsih, 2021). In-person communication makes the education more active and engaging both for the students and the faculty. The greatest limitation of this and other relevant methods, is the lack of schedule flexibility. In consideration of the accelerated pace at WPI classes due to the shortened 7-week terms in WPI, this restraint may become a great problem for the long-term sustainability of our modules. One of the possible solutions might be an implementation of the modules in the asynchronous, or fully online, format. An asynchronous format is an accredited method of delivery of one educational module per course which does not underperform in terms of learning efficiency (Farina Jr, 2017). In addition, according to the comparative research of online and in-

person education in terms of learning outcomes performed in 2016 by the faculties of Yarmouk University, Jarash University, and the University of New Haven, their "results showed the superiority of the online learning methods over traditional one" (O Nahar, 2016). Therefore, we would also like to evaluate which of the delivery methods might work best in terms of our IQP and future implementations of HCD educative modules to the WPI BME schedule.

The goal of this IQP was to develop a framework for the implementation of a sustainable HCD curriculum in the Biomedical Engineering Department at Worcester Polytechnic Institute (WPI). Our IQP piloted a progressive HCD curriculum across the BME department using Bloombergberg's Model as a scaffold for the educational goals that should be achieved after completion of HCD content at each grade level. In this paper, we discuss our methodology for the development and implementation of such modes of delivery and our analysis of the efficacy of our project through pre –and –post-survey responses from students.

II. Literature Review on Healthcare Disparities Education

2.1 Significance

Health disparities are defined by the World Health Organization (WHO) as "preventable differences in the burden of disease, injury, violence, or opportunities" among certain populations (*Health Disparities | DASH | CDC*, 2022). Certain population are at a higher risk of receiving lesser health outcomes, and this can be defined by factors such as poverty, location of residence, educational quality, and inadequate access to healthcare (*Health Disparities | DASH | CDC*, 2022). Unequal healthcare can lead to healthcare disparities (HCD) in these populations—a major contributor to health disparities. While health disparities are gaps or differences in health

outcomes when comparing one group to another, healthcare disparities are differences in access, availability, and quality of medical care within populations (*Disparities)*.

Lack of access and delivery of medical services can have significant impacts on an individual's health. Reports from the WHO reveal that over half of the world does not have access to essential health services, and about one-hundred million people will be subjected to extreme poverty due to costs of health (Tracking Universal Health Coverage, 2017). Even post-industrialized countries like the United States with abundant resources, modern medical facilities, and qualified staff face substantial HCDs (Wayne, 2012). Early recognition and awareness of disparities is a main component in mitigating them. (Thorton, 2016). Reducing HCD requires raising awareness early on, particularly through formal education in the undergraduate curriculum (Thorton, 2016). Without awareness of the inequalities that exist for vulnerable populations in medical care, undergraduate students may enter the workforce seemingly unprepared to deal and engage with HCD. However, there is currently a lack of literature and research addressing HCD education and implementation.

With trends in data displaying inequalities in healthcare have not improved amongst some populations in the United States, the need for undergraduate HCD education is increasing (2019 National Healthcare Quality, 2019). One such example of a prevailing inequality in health is infant mortality rates are 60% higher for Alaskan Natives and Native Americans than the rates for their white counterparts (*CDC Report Documents Health Disparities*, 2022). Medical professionals working directly with patients are not the only individuals who contribute to HCD. Those who develop treatments also risk contributing to them. Findings in a study by Vazquez demonstrate professionals in STEM-related careers exhibit an ongoing lack of HCD awareness and are uninvolved in education and/or research on the topic, accentuating the current demand

for educational initiatives (Vazquez, 2018). Biomedical engineering is a STEM discipline that directly impacts and interacts with the medical field, and dramatic advances in patient treatments are available due to this profession (Saha, 1997). Biomedical engineering and healthcare are two different fields; however, the consequences of biomedical engineers' decisions can also impact health outcomes (Monzon, 1999). As a result, biomedical engineers need to understand how their field of study interacts with the healthcare field and how products can possibly lead to HCD.

2.2 Healthcare Disparity Education Across the Country

Addressing healthcare disparities in undergraduate programs across the country is not currently standardized. Studies proposing methods to address healthcare disparities education in biomedical undergraduate programs are limited, but several attempts have been made in various universities and educational initiatives. The Department of Biomedical Engineering at The City College of New York (CCNY) conducted a multiyear study aimed at increasing BME students' engagement in inequalities in health (Vazquez, 2017). Didactic modules were integrated at every grade level in courses required for BME, and capstone design projects associated with disparities were delivered to the students. Modules included lectures, case studies, and written assignments. Results from the study revealed BME student interest in the modules dramatically increased from 22% interest during the first year, to nearly 80% by the second year and >90% during the final year of the project (Vasquez, 2017). A study at Georgia Institute of Technology confronted the need for healthcare disparity education through frequent opportunities for BME students to learn about having an inclusive mindset in their interactions, problem-solving, and designs (LeDoux, 2021). Students found non-inclusive designs and shared personal accounts of when either themselves, or someone they know, was adversely affected by a non-inclusive design. Of

the 121 students who took part in the study, 34% were more motivated and empathetic about the topic after connecting it with a personal experience (LeDoux, 2021).

In addition to initiatives in engineering departments, medicine-focused departments in both undergraduate and upper-level institutions have undertaken healthcare disparity education. The University of Chicago Pritzker School of Medicine introduced a five-day course called "Health Care Disparities in America" to all current students (Vela, 2008). Over the five days, students attended lectures, took part in group discussions, made posters on relevant topics, and read assigned readings. The course effectively taught healthcare disparities to the students who participated by increasing their factual knowledge on the subject, and it was given the highest overall rating of all courses at the institute (Vela, 2008).

2.3 Healthcare Disparity Education at WPI

According to WPI's 2020 First Destinations Outcome Report, increasing numbers of biomedical engineering graduates are entering professions related to healthcare (First Destination Outcome Report, 2020). Therefore, biomedical engineers are in a unique position to influence trajectories in healthcare disparities. It is crucial for a formal healthcare disparities curriculum to be implemented into the biomedical engineering undergraduate program to mitigate such disparities in their future careers. Presently, WPI lacks a systemic healthcare disparities curriculum within the biomedical engineering department. Findings from a previous Interactive Qualifying Project (IQP) at WPI show that both the students and professors in biomedical engineering recognize the importance of healthcare disparities in their profession and that there is currently a deficiency in such a curriculum (Cordner, 2021). Notably, the same IQP surveyed a sample of 461 students and found that 76.1% had not encountered healthcare disparities content

in classes at WPI across all graduation years. They piloted healthcare disparities modules and found that the majority of students who took part in the study demonstrated an increased understanding of the topic after only one in-class session (Cordner et al., 2021). Even though the previous IQP demonstrated a distinct need for education on HCD and that formally introducing the topic to students can increase their awareness of such issues, the project has limitations. One such limitation was the HCD education was not sustainable because the IQP team delivered the content to the class and this was not continued with the conclusion of the IQP. Additionally, the content developed would be repetitive if implemented into the current BME curriculum, as only one educational presentation was created rather than different presentations created for each course level.

2.4 Modes of Delivery

Based on existing attempts to address HCD in both biomedical engineering programs, there are two main modes of delivery that can be effective for implementation within an engineering curriculum – a required standalone course or content dispersed across a curriculum (Jackson, 2015). A required standalone course for engineering students would be a class solely dedicated to topics of HCD. Standalone courses on similar topics, such as the broader concept of ethics and health disparities, have been piloted in numerous educational institutions and departments, and would ensure that all students are receiving a sufficient depth of knowledge on the topic. One method for integrating such a course into an engineering department is to have humanities and philosophy professors aid in teaching the class. Texas A&M is one undergraduate university that has been successful at integrating a required standalone ethics course for engineering students by having a philosophy professor teach an ethics course with an

engineering professor as a partner (Rabins, 1998). While standalone courses like Texas A&M's allowed the students to have full emphasis placed on the topic at hand, in this case, there are multiple drawbacks to the inclusion of a standalone course. One such drawback is the challenge of making a requirement for a course in an engineering student's schedule, which is already filled with required courses.

WPI currently has multiple standalone ethics courses that can be taken by any WPI student including courses such as Bioethics (PY2713), Ethics (PY/RE2731), Philosophy and Ethics of Computer Games (IMGD2001), and Leadership, Ethics, and Social Responsibility (OBC4367). As it stands across all engineering disciplines at WPI, only robotics engineering (RBE) majors are required to take an ethics, or "Social Implications" course (*WPI 2021-22 Undergraduate Catalog*, 2022). With an ethics course being a requirement for an RBE major, it calls for the engineering departments at WPI to investigate why all engineering disciplines do not currently have this requirement and why it could not be made a requirement in the future.

Content integrated across a curriculum also has advantages and disadvantages. This mode of delivery allows content to be integrated throughout the entire duration of an undergraduate student's curriculum, reinforcing knowledge and ensuring topics covered are not seen as peripheral to an engineering student's major (Jackson et al., 2015). In this mode of delivery, professors within the BME department would incorporate relevant HCD lectures and content into their courses. As students moved through their required engineering course levels, the HCD content would also build upon itself to provide students with a comprehensive HCD curriculum by the end of their undergraduate studies. One advantage to this approach is BME professors, as experts in their field, could provide credible and relevant content and personal experiences directly related to the topic of HCD. One drawback, however, is a professor might not feel

confident in their own knowledge of HCD and would not be comfortable with teaching it (Jackson et al., 2015). At WPI specifically, the seven-week term schedule allows for little flexibility within a professor's course schedule to incorporate content on HCD.

2.5 Bloomberg's Model: Taxonomy of Knowledge

Our IQP team chose to incorporate a HCD curriculum across the BME department curriculum based on Bloomberg's taxonomy. This curriculum delivery method would allow students at each course level to be continuously exposed to and engaged with HCD education, enhancing their knowledge and skills related to HCD. This method would also ensure every BME student receives education on HCDs in their undergraduate curriculum, instead of current standalone courses that are not required by the BME department.

Teaching BME undergraduate students about HCD at all grade levels requires an educational framework for what a student needs to accomplish in order to fully learn a concept and apply what they know. Bloomberg's Model lays out a taxonomy of knowledge that can be applied to the HCD curriculum. There are six levels to this framework: inform and remember, understand, apply, analyze, evaluate, and create (Figure 1). Each level lays out how a student should progress through and be introduced to a topic, allowing them to then apply their learned knowledge. At the most basic level, "remember," a student will move to the level of the taxonomy once they are able to recognize and recall the information presented to them. At the "understand" level, a student can begin to demonstrate a comprehension of the information and should be able to interpret, exemplify, classify, summarize, compare, and explain concepts. At the next level, "apply," a student can execute a demonstration of their knowledge by applying and implementing it. After being able to apply knowledge, a student moves onto the "analyze"

level in which they will be able to differentiate, organize, and attribute their learned knowledge. A student will then be able to "evaluate" additional topics and be able to check and critique the topics based on what they know. At the final level of "create" a student should be able to generate, plan, and produce based on what they know (*Bloomberg's Taxonomy*, 2022.) Bloomberg's Module of educational objectives can be applied to develop a curriculum across the BME department.

Applying Bloomberg's Model to the BME curriculum, at the most basic level, students must be informed about and understand what healthcare disparities are. Various initiatives have been conducted to educate students about HCD and have developed a baseline of how to define HCD and other terms related to HCD. One such initiative is by The Association of Program Directors in Radiology (ADPR), a medical residency and fellowship educational program. ADPR created a HCD curriculum, along with a "Healthcare Disparity Glossary" that includes the definition of HCD and relevant terms. This glossary provides students with the informational background required to understand not only the definition of healthcare disparities, but the various aspects that contribute to them (DeBenedectis, 2020). The terms included in this glossary that our group will be using include: vulnerable populations, social determinants of health, implicit bias, cultural competency, and health equity. Additionally, the 2021 IQP determined comprehensive terms that can be applied to biomedical engineering and the life sciences. Multiple terms overlapped with the ADPR Healthcare Disparity Glossary; however, the following terms can be introduced to biomedical engineering students to build on their basic knowledge of disparities with terms that are relevant to their field. These terms include skewed research populations and missed and/or misdiagnosis. (Cordner, 2021). Our group has also added the engineering design term "human-centered design," as it is a major consideration in the

engineering design process that can help mitigate HCD caused by engineers. The following sections define the terms that are used throughout our IQPs HCD curriculum.

2.6 Terms from ADPR Healthcare Disparity Glossary

Skewed Research Populations

It is not uncommon that minority groups are underrepresented and excluded from many research studies. There are two types of research studies that require human subjects—clinical trials and observational studies. Clinical trials are research studies that randomly assign different participants or groups to one or more health-related interventions allowing the researcher to evaluate the direct effects of the health outcomes (Clinical Trials, 2015). These can be positive or negative health outcomes, including pharmaceuticals, surgical procedures, and medical devices. Clinical trials are required for FDA approval/regulation. In order to speed up the process of FDA approval, many experiments overlook socially disadvantaged populations and look for more "clean data" (Mosenifar, 2007). This clean data typically arises from majority groups - further excluding minorities and increasing the chance of healthcare disparities from arising and being a societal norm. A drug can be mass produced once it is declared "safe" based on the studies that the researchers had run with their "clean data." Unforeseen side effects can occur in minority groups that were not included in the study - as this could have produced unfavorable results in the "testing phase" (Mosenifar, 2007). One major example of this is under-testing on minority populations in cancer research studies. A study conducted in 2015 found that even though the NIH Revitalization Act has been in place since 1993, which required all federally funded research to include minority populations and women, out of more than ten-thousand cancer

studies less than 2% included enough minorities to be considered relevant (University of California - San Francisco, 2015).

Missed and Misdiagnoses Based on Disparities in Healthcare

Inaccurate medical diagnoses make up a large part of healthcare disparities and greatly contribute to major discrepancies in life expectancies among marginalized groups For example, Blacks experience higher mortality rates for heart disease, cancer, diabetes, and perinatal conditions (Kochanek, 2013). There are many reports from the African American community indicating that their medical needs are not taken as seriously as other patients. For example, they are more likely to have their reports of pain or other symptoms dismissed without any further investigation (Hoffman, 2016). Symptoms can vary based on race and ethnicity, as showcased by the African Americans' reports, and a working knowledge among healthcare professionals to address this is needed.

In addition to symptoms being missed by medical professionals, there is a lack of feelings of trust in patient-provider relationships, mostly for patients from minority groups. This can contribute to medical misdiagnosis and inconsistent treatment of the patients. The lack of trust in minorities often stems from historical views and situations. One example of this is the Tuskegee Syphilis experiments in which African Americans were unethically used as test subjects to track disease progression of syphilis. Even when the recommended treatment for syphilis, penicillin, became widely available test subjects such as African American men were not given these treatments. Therefore, experienced adverse health issues and the disease became more widespread in those communities (Smedley, 2003). In the section "Implicit Bias in Healthcare" we discuss modern examples of mistrust perpetuating in healthcare in the United States.

Vulnerable Populations

Vulnerable populations are populations that experience obstacles resulting from characteristics that define them such as age, gender, socioeconomic status, ethnicity, sexual orientation, and/or disabilities (DeBenedectis, 2020). These characteristics have consistently been risk factors throughout history for people in these groups. While everyone is at risk for developing sickness, these groups have a higher relative risk. In relation to health, these groups experience increased instances of poor health— physically, socially, and psychologically (Aday, 1994). Patients most at risk include those who are uninsured, minorities, elderly, or socioeconomically disadvantaged (Ortiz-Pedroza 2021). An example of vulnerable populations receiving lesser outcomes in health is national infant mortality rates, with an infant mortality rate 60% higher for indigenous populations in comparison to their white counterparts (National Academies of Science, 2017).

Social Determinants of Health

Currently in the United States there exist social structures that promote poor health and contribute to lesser health outcomes (Auerbach, 2019). Social determinants of health (SDOH) are defined by Healthy People 2030 as social environments where people carry out their lives— where people play, live, learn, and worship— that affect both quality of life and health outcomes (Healthy People 2030). There are five domains of SDOH— economic stability, neighborhood and built environment, education access and quality, social and community context, and health care access and quality. For the purpose of this study, SDOH will be analyzed in the domain of health care access and quality. A prominent example of this kind of determinant is an individual

who is diagnosed with diabetes; however, that individual cannot afford to pay for healthy—low sugar and unprocessed—foods meaning they cannot properly manage and control their health outcome (Auerbach, 2019). According to recent evidence in the Accountable Health Communities Model, gathering "clinical-community linkages" is a main proponent in combating SDOH (Accountable Health Communities Model, 2021). This means identifying unmet needs such as food insecurity and/or unstable housing that could contribute to an increased risk of developing chronic conditions or inability to properly treat and receive care (Accountable Health Communities Model, 2021). Biomedical engineers design new technologies to be implemented into the medical field, and must utilize inclusive research methods when doing so to account for social determinants of health (Oh, 2015).

Implicit Bias in Healthcare

Implicit biases are unconscious associations made by an individual that can potentially lead to negative assumptions and evaluations based on factors such as race or gender (Fitzgerald, 2017). These occur between groups or categories and a particular evaluation of such. A prominent example in research and in the field of psychology is the category of being Black associated with the category attribute of being violent (Fitzgerald, 2017). In a systematic review of 42 studies, implicit biases were found to be most prominent in patient-provider interactions and treatment decisions (Fitzgerald, 2017). Specific examples include Black patients are less likely to be prescribed pain medication in comparison to White counterparts, and women's symptoms of pain are taken less seriously by physicians (Shuck, 2017; Bedford, 2018). Implicit biases affect minority groups the greatest and can be linked to unequal healthcare and statistically shorter lifespans (Zestcott, 2016).

Studies have shown implicit biases can impact the judgment and behavior of healthcare professionals towards their patients (Zestcott, 2016). These are often deeply rooted in historical views of groups such as minorities and women, that unconsciously seep into decision-making (Zestcott, 2016). Despite the majority of healthcare workers claiming “quality” is central to their line of work, the quality of care across all patients is not equal (Byrne, 2015). This is evident in countless studies displaying unequal outcomes for certain conditions across different groups. For example, HIV/AIDS, diabetes, cancer, and cardiovascular disease have statistically less successful outcomes for minorities such as decreased recommendations for proper disease treatments and higher mortality rates (Riley, 2012; Graham, 2015).

Cultural Competence

The Office of Minority Health defines cultural competence as “... a set of congruent behaviors, attitudes, and policies that come together in a system, agency, or among professionals that enables effective work in cross-cultural situations" (Cross et al., 1998). Increasing cultural competence has recently been promoted as a strategy to improve disparities in health care as demographic trends in the United States show growth in minority populations' competence (Harris, 2010; DeBenedectis, 2020). A situation in which this need might arise is an interaction between a white physician and a minority patient, as shown in a study by Schillinger et al. (Schillinger, 2004). The study examined 116 interactions between Spanish-speaking individuals and 48 physicians with interpreter services present and displayed physicians with higher Spanish-speaking abilities and cultural competence had more successful patient visits (Schillinger, 2004). This study displays the importance of cultural competency in relation to the treatment a patient receives. Healthcare professionals experience cross-cultural situations

frequently in their professions and must be prepared to treat patients with diverse social and cultural backgrounds (Boutin-Foster, 2008).

Health Equity

The Center for Disease Control (CDC) states health equity will be achieved when all individuals have the opportunity to "attain his or her full health potential" (Center for Disease Control, 2021). Currently, health equity is far from being fully achieved, even though it is consistently cited as the most important goal to achieve (Zimmerman, 2019). The World Health Organization calls for governments to address health inequity by providing "adequate housing, nutritious food, safe working conditions, and quality health services" (Murray, 2015). Health equity is defined in the APDR Healthcare Glossary as a person having just and equal access to health services, and the opportunity to successfully maintain and improve their health (DeBenedectis, 2020). Trends show race, gender, and income are indicators of lesser health outcomes (Zimmerman et al., 2019). A study by Zimmerman et al. demonstrated this trend by examining health across race, sex, and income in the United States between 1993 and 2017, revealing an overall lack of progress for health equity (Zimmerman, 2019). Although the "Black-White gap" showed improvements, disparities for those with low incomes actually increased.

2.7 Additional Glossary Term: Human-Centered Design

Design is a central part of the engineering profession in which an engineer must identify and solve a problem to address a need (Dym et al., 2005). For biomedical engineers specifically, products designed by this type of engineer will directly impact an individual using the medical-centered product, and as such, people who will use the product must be considered throughout

the design process. Human-centered design is a process that calls for users of a product to be "the center of technical system designs" (Putnam, 2016). All users must be considered in the design process, be informed about the product, and be able to use it. Keeping this process in mind when designing a product can help to mitigate HCD. By having the engineer consider who will be using the product, and whether all users will be able to access and use the product equally, they will be able to recognize potential flaws in their design plan or sample population for testing and adjust accordingly to avoid creating a potential HCD.

III. Methodology

3.1 Introduction and Background

For this Interactive Qualifying Project (IQP), we developed a multi-level healthcare disparity (HCD) curriculum to be piloted across all course levels at WPI. Previous IQPs concluded that there was a lack of a formal HCD education in the BME curriculum, as well as a need for further efforts to include such an education **(**Cordner, 2021). Our group expanded upon this prior work by creating HCD modules for each BME course level accessible through WPI's educational online platform, Canvas. A HCD module is a collection of informational slides, case studies, and an in-class discussion or written assignment on the case studies. Modules at each course level built upon a student's knowledge of HCD through the educational scaffolding of Bloomberg's Model. Throughout the HCD modules at each course level, students were introduced to the broad topic of HCD in connection to ethics, then gained knowledge and skills on how to mitigate HCD in BME.

HCD modules were piloted once at each course level, except for the 3000 level, which was piloted twice. This resulted from BME professors' availability to incorporate HCD modules into their course. Surveys were administered before and after a student completed a HCD module. Through analysis of the modes of delivery and responses on the pre- and post-surveys, our group's goal was to identify strengths and weaknesses in each mode of delivery and the efficacy of the HCD modules to create a framework for the BME department to establish a sustainable HCD curriculum. All content was developed in concert with our faculty advisors.

3.2 BME Faculty Climate Survey: Purpose and Analysis

To determine if BME professors felt there is a need for HCD and were willing to implement in their course, an online survey was distributed to BME professors during a BME department meeting at the start of WPI's C-term. The survey was a total of nine questions, and the purpose was to provide our IQP group with qualitative and quantitative data on the BME professors' interest in the topic of HCD, whether they already implemented content on HCD, and what mode of delivery they believed would work best for implementation of our curriculum. The survey also measured the progress made in previous IQP projects in relation to healthcare disparities education at WPI, validating the need for our IQP. A copy of the survey can be found in Appendix A.

A total of 11 responses were collected, with five professors choosing to remain anonymous. Of the sample population (n = 11), 81.5% (n = 9) indicated they do not believe healthcare disparities are covered in enough depth across a BME student's curriculum, and 63.6% (n = 7) indicated they do not currently cover healthcare disparities in their courses. Reasons for not including content on HCD could be indicated with an optional write-in

response and a total of five responses were collected. Three responses indicated there is not enough time in WPI's seven-week term schedule to include HCD content. The results from the survey indicated that professors generally felt there is a need for HCD education and that a systemic HCD education would help them to accomplish this in a limited seven-week term.

In addition to providing data on the professors' level of interest in HCD content within their courses, the survey provided information on how the professors would like to pilot our HCD curriculum. A total of 91% (n = 10) of the professors indicated that they would like to cover HCD in their courses. No professors indicated that they could not fit HCD content into their course, with seven indicating they could use one lecture period (about 50 minutes) and three indicating they could use half of a lecture period (about 25 minutes) for HCD content. A total of 72.7% (n = 8) expressed they could moderate in-class discussions and activities based on case studies if there was a guide and prepared materials to help them. Responses from the professors displayed our HCD curriculum needed to be based around in-class discussions and activities with relevant case studies.

3.3 Implementation

Implementation of our HCD modules had three phases. The first phase was for students to complete the pre-survey, prior to receiving any educational content on HCD. The second phase was for students to complete the educational modules. Educational modules consisted of two parts – a HCD Course Level Overview and a review of pertinent case studies. Students in courses that piloted our modules in the in-person mode of delivery read and reviewed the HCD Course Level Overview prior to class. The students then took part in an in-class discussion based on case studies related to content in the HCD Course Level Overview. Students in

courses that piloted our modules asynchronously read the HCD Course Level Overview and case studies on their own. Due to time limitations of the project, asynchronous students were not asked to complete an assignment based on the case studies. The third phase of implementation was for students to complete the post-survey after completion of the HCD educational modules.

3.4 Educational Modules: Development

Incorporating sustainable HCD modules into the BME curriculum required developing content for a comprehensive HCD curriculum across all course levels. We define a module as the collection of informative HCD slide presentations, one or two relevant case studies, and an in-class discussion. In order to develop content for classes at each course level, our group used Bloomberg's Taxonomy of Knowledge to establish learning goals related to HCDs for BME students. We then conducted separate meetings with three BME professors in order to gain insight and guidance on the learning goals, as well as to discuss the current climate of HCD education within the BME department, what each professor thought the BME department needed in order to improve HCD education, and to gather content for the HCD modules. At each course level, students should take part in one HCD module by reading and learning from the HCD slide presentation and attending an in-class discussion on HCD. The module's content at each course level consisted of an informational HCD Course Level Overview and case studies. Four separate HCD Course Level Overviews were developed for each course level. These modules build on top of one another following the organizational scaffolding in Bloomberg's Model (Anderson, 2014). According to this model, students must first learn about

HCD and then go on to evaluate and create with a skill set for recognition and prevention of HCD (*Bloomberg's Taxonomy*, 2022).

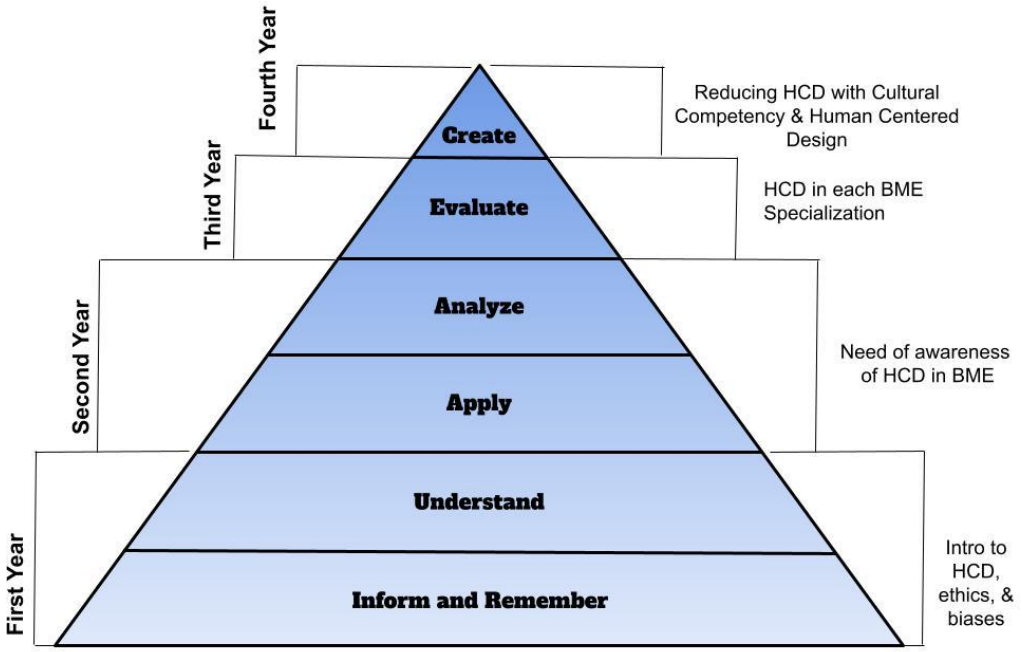

Figure 1. *Bloomberg's educational model and applied to each grade level in the BME undergraduate curriculum*

Applying this model to develop four learning outcomes for each undergraduate student in the BME curriculum, students must (1) be informed about the definition of HCD in the context of the broad concept of ethics and health disparities; (2) be introduced to the need of awareness of HCD within BME and apply previous HCD knowledge to BME-specific case studies; (3) evaluate HCD that can arise within each BME specialization; (4) create within engineering design processes while using a skillset to prevent and mitigate HCD (Figure 1). Each learning outcome was applied to the four course levels at WPI—- 1000, 2000, 3000, and 4000. The 1st

year students at the 1000 course level learned about the broad concept of ethics, health disparities, and healthcare disparities. The 2nd year students at the 2000 course level were exposed to HCD in the field of biomedical engineering. The 3rd year students at the 3000 course level were exposed to HCD within the three biomedical engineering concentrations—biomaterials, bioinstrumentation, and biomechanics— and developed an understanding of how to recognize and prevent HCD. The 4th year students at the 4000 course level were given a skill set for recognition and prevention of HCD in their own research projects, such as the MQP at WPI, and future careers. The 4th year students were also introduced to the terms "cultural competency" and "human-centered design" to provide them with additional tools for mitigation of HCD when they go on to create in their MQP, other future research, or in a career (Figure 1). In order to accomplish the learning outcomes at each course level, a student should be provided with information related to the outcome and given an opportunity to use metacognition in the analysis of case studies. Metacognition "denotes in-depth thinking in which cognitive processes involved in learning are actively controlled" *(What is metacognition?,* 2013). Studies have shown students who are aware of their thinking processes as they learn and analyze are more self-aware *(What is metacognition?,* 2013).

1000-Level HCD Module Development

The goal of the 1000-level HCD module was to inform students about HCD and help students understand that HCD still perpetuate. In order to accomplish this, our group created a definition and example-based 1000 HCD Course Level Overview using terms from the ADPR HCD Glossary: social determinants of health, health equity, health disparities, and healthcare disparities. Additionally, our group met with a BME professor, Professor Reidinger, who

instructs a BME Design course (BME3300) involving deign considerations of a biomedical engineer. We met with Professor Reidinger on two occasions—once to discuss the 1000 level and 2000 level HCD modules and again to discuss the 3000 level and 4000 level HCD modules. Professor Reidinger explained 1000 level students should learn about the "big picture" and "well-known" instances of extreme cases where HCDs resulted from a particular study or invention. For example, she suggested we use the terms selected from the ADPR HCD glossary and to include current statistics of HCD within the United States. Furthermore, she suggested we provide students with the example of the Tuskegee Syphilis experiment, as this experiment displays an extreme case of ethical dilemmas when performing tests for the syphilis disease. According to Professor Reidinger, when providing students with extreme cases, students should be able to recognize the blatant neglect of ethics that took place and can later apply such recognition to "tougher problems," such as design considerations of a sneaker.

2000-Level HCD Module Development

The goal of the 2000-level HCD module was to show students how HCD apply to the field of BME and to provide them with examples of HCD that have resulted from BME designs and inventions. Our group developed a 2000 HCD Course Level Overview explaining how the field of BME interacts with the field of healthcare, that many BME inventions do not always equally benefit all people, and that biomedical engineers have a responsibility to consider ethics. Professor Reidinger suggested we introduce students to the Biomedical Engineering Society Code of Ethics to show BME students that biomedical engineers have an established code of ethics. This code of ethics makes all biomedical engineers have an obligation to learn about and consider ethics, and therefore, HCDs (*Biomedical Engineering Society*, 2022). She

also suggested it is important we show students that inventions are not always tested on representative populations which can result in HCDs. For example, she provided the example of automobile test dummies being modeled only after the average sized man up until the year 2011. As a result of this, seatbelts are not as affective for women, with women being 17% more likely to be killed in a car crash (Brooke, 2021).

Our group also met with Professor Albrecht, a BME professor for the Introduction to Bioinstrumentation course (BME2210), prior to piloting our HCD modules in his class. Professor Albrecht had piloted previous HCD IQPs in his course and believes HCD education is important but lacking within the current BME curriculum. He commented on WPI's seven-week term system, highlighting the difficulty professors face trying to incorporate additional material to their courses, and believed utilizing Canvas as an archive of HCD materials for professors to use would be a good way to keep the HCD curriculum sustainable. Additionally, Professor Albrecht discussed the importance of connecting case studies to the biomedical engineering principles being taught in specific courses, as it challenges students to directly apply their learned knowledge on a subject to a problem involving potential HCDs. He recommended our group use the example of a pulse oximeter in his BME2210 course discussion and to include this example in the 2000 HCD Course Level Overview. This device uses bioinstrumentation techniques in order to detect oxygen levels within a patient's blood; however, individuals with darker skin consistently report incorrect readings due to the device's inability to perform light reflection detection on darker skin tones. Professor Albrecht also suggested our group discusses other factors that could influence why some HCD occur. For example, he explained money and corporations could have an effect on the populations that are tested in clinical trials, as clinical trials are extremely expensive and the end goal of

corporations is to gain profit. He pointed out that engineers should be aware of this and should be able to answer the question of whether cutting costs in certain design processes is worth it when ethical dilemmas arise.

3000-Level HCD Module Development

The goal of the 3000-level HCD module was to learn how HCD can arise within each BME specialization and to learn how the technology produced from each specialization interacts with the medical field. Our group gathered examples of HCD within each BME specialization and delivered them to students through presentation slides in the 3000 Course Level Overview. Our group discussed the 3000 level HCD modules with our IQP advisor and BME department head, Professor Billiar, to outline what students in the biomaterials specialization should be informed about. Professor Billiar is an expert in artificial heart valve engineering, an engineering process rooted in the BME biomaterials specialization, and provided our group with example studies and case studies on HCD that could arise when engineering artificial heart valves. Case studies for the biomechanics specialization were provided by Professor Reidinger and included exoskeletons being designed for "one size fits all," even though women make up to 50.4% of workers ("Ushering in a New Era of Exoskeletons Designed for Women," 2020). Case studies for the bioinstrumentation specialization were provided by Professor Albrecht and included the pulse oximeter example, and race-based calibration errors for creatinine levels in blood (Murthy et al., 2005).

4000-Level HCD Module Development

The goal of the 4000-level HCD module was to show students how to reduce HCD in their future projects and to introduce them to the definitions of cultural competency and human-centered design. As previously described, cultural competency and human-centered design can be used to help engineers design products that consider all populations and are centered around the user. Our group developed the 4000 Course Level Overview by providing definitions of cultural competency and human-centered design, providing an example of where these definitions can be applied, and how the 4000 level students can use their knowledge to mitigate HCD in their future projects—both at WPI and beyond graduation. Professor Billiar helped our group to develop content for explaining to 4000 level students how they can consider HCD in their MQPs. He explained students need to write at least one paragraph in their MQP discussing the ethical considerations of their project; however, most project teams struggle to write this paragraph. As a result, he suggested we find a previous MQP and show students where cultural competency and human-centered design could have been used by the MQP group. Our group found a BME MQP related to sports shoe engineering to resist knee and ankle injuries and used cultural competency and human-centered design to outline what the MQP group could have written about in their one-paragraph explanation of ethical considerations in their final MQP paper (Sheldon et al., 2015).

3.5 Educational Modules: Delivery

HCD module content was accessible to professors via Canvas. Canvas is a learning management system website that students at WPI utilize daily to access course materials such as recorded lectures, assignments, course content, and online quizzes and exams. Professors may also utilize it by posting such materials for students to the Canvas course page. Features

within Canvas allow content from one course page to be transferred and uploaded to another. Our Canvas page will act as an archive of materials for HCD content. Additionally, using online platforms in educational processes have proven to be an easy and effective way of learning (Means, 2018). According to the faculty survey, BME professors also indicated they would like to have access to content for their classes and Canvas is a platform that will allow them to do it in the quickest and the most efficient way.

Based on the ADPR Healthcare Disparities Curriculum, four in-person sessions are suggested for an individual to complete the minimum HCD curriculum requirement (DeBenedectis, 2020). Applying this to the BME undergraduate education at WPI, students should partake in at least one module per academic year to gain a working knowledge of the topic. Additionally, our group decided to incorporate the modules across a curriculum by including them within classes at every course level. “Across the curriculum” refers to HCD content being delivered at each course level within BME-specific courses. Previous IQPs at WPI and initiatives at other institutions have shown this method to be most effective in carrying the knowledge learned throughout each grade level and avoiding making the topic of healthcare disparities peripheral to the BME courses (Jackson, 2015; Cordner, 2021).

Our goal was to pilot HCD modules within two courses at each course level. We reached out to all professors teaching BME courses during C-term at WPI via email. A total of five professors responded and agreed to implement our modules. The courses that implemented our modules were as follows: Introduction to Programming in MATLAB (BME1004), Biomedical Signals, Instruments and Measurements (BME2210), Skeletal Biomechanics Laboratory (BME3503), Solid Biomechanics Laboratory: Techniques (BME3505), and Biomechanics (BME4504). Based on the courses that piloted our HCD modules, we developed relevant

discussions and case studies for each course. For example, BME4504 discussed a case study about possible HCD that could arise in the development of prosthetics (a product produced using biomechanics), while BME2211 discussed a case study involving a pulse-oximeter sensor (a product produced using bioinstrumentation). Relevant case studies allowed the students to directly apply their newly-learned knowledge from the HCD Course Level Overview to a pertinent topic connected to their course. After the professors agreed to pilot our modules, we met with them separately to gather feedback on the HCD Course Level Overviews, how they would like to implement our modules, and on the chosen case studies for their course. Based on the feedback given, we adjusted our HCD content and catered to the necessary mode of delivery for each course.

Table 1.

Biomedical Engineering Healthcare Disparities Curriculum Pilot Courses

Course #	Course Name	Professor	Mode of Delivery
BME 1004	Intro to MATLAB	Songbai Ji	Asynchronous
BME 1004	Intro to MATLAB	Taimoor Afzal	Asynchronous
BME 2210	Bioinstrumentation	Dirk Albrecht	In-class discussion
BME 3111	Physiology and Engineering	Sakthikumar Ambady	Asynchronous
BME 3503	Skeletal Biomechanics Lab	Funmi Ayobami	In-class discussion
BME 3505	Biomechanics Lab - Techniques	Ali Salifu	Asynchronous
BME 4503	Biomechanics	Karen Troy	In-class discussion
BME 4701	Cell and Molecular Bioengineering	Catherine Faye Whittington	In-class discussion

Due to the limitations of the 7-week terms at WPI, multiple modes of delivery were piloted in the eight participating courses, per the professor's request. BME4504 and BME4701 were delivered in a full class period in-person discussion. Both BME2210 and BME3505 were delivered in half-

class period in-person discussions. The in-person mode of delivery suggests active communication between the faculty and students which allows for the building of emotional connections which usually bring a greater interest in the discussed topic (Ningsih, 2021). To address the needs of all the students, the lectures in in-class discussion format were provided in two formats simultaneously: while the instructors were showing slides, explaining the material, and answering questions, all activity was also streamed via one of the stream platforms (usually it is Zoom or Echo360). Finally, BME1004, BME3111, and BME3503 were delivered fully remote via Canvas (Table 1). This approach allowed us to cover a wide range of material within a condensed amount of time. As some of the faculty were not able to dedicate lecture time to the Healthcare Disparities Educative modules, the material was provided in the online asynchronous mode. Each iteration provided relevant data for investigation of which mode of delivery works best, as well as the most successful duration of time for discussing the topic of HCD. In courses that had an in-person component, students were assigned to read and review the HCD Course Level Overview prior to class in order to prepare them to engage with the case study discussion. During the in-person class, a case study was read aloud to the students. Students were then asked to participate by answering various questions lead by our IQP group based on HCD.

The asynchronous delivery method suggests that students, while having an access to the relevant information, are actively involved in self-education. This method suggests a minimum amount of interaction between the faculty and students. In courses that were fully remote, students had to read the HCD Course Level Overview on their own and complete a short written assignment based on a relevant case study. Supplemental content, such as relevant scholarly articles on HCD in BME, were also provided for the students to allow them to further investigate the topic of HCD in BME. The written assignment was a two-paragraph response to the case

study that asked students to identify where HCD could arise within the case study and to provide a solution for preventing a possible HCD. Additionally, the written assignment served to replace the in-class discussion for the students who took the HCD completely online.

3.6 Pre-Survey of Student Participants: Purpose

Before students began the HCD module, an anonymous survey was distributed via the online surveying platform Qualtrics to students within the courses piloting our IQP. Our IQP gained IRB exemption status from the WPI IRB exemption board prior to the distribution of the surveys. The purpose of the pre-survey was to gain quantitative and qualitative data of the students' understanding of HCD. Surveying is shown to be a time-effective, reliable method of inquiry to gain knowledge on chosen populations when conducting social research (DeCarlo, 2018). The survey included a total of eight questions pertaining to whether or not the students had previously learned about HCD at WPI; if they thought HCD are important for their future profession; and if the topic of HCD had been formally covered in previous courses at WPI. The same HCD Pre-Survey was given across all course levels. A copy of the survey can be found in Appendix A.

3.7 Post-Module Survey of Student Participants

After completion of a HCD module, a second anonymous survey was distributed via Qualtrics to students who completed the HCD modules. A separate survey for each grade level was developed with the purpose of gaining data on whether the developed course learning objectives for each course level were accomplished. A copy of each survey can be found in Appendix A. The 1000 Level HCD Post-Survey included a total of seven questions. The

questions asked students whether or not they could define a HCD, and if they could provide an example of one. The 2000 Level HCD Post-Survey included a total of fourteen questions. The questions for this survey asked if students believed HCD were important after the modules, if the modules helped them to understand that HCD are present in BME, and if they thought the HCD modules were engaging. The 3000 Level HCD Post-Survey included a total of 12 questions, and asked students if they could name a particular HCD within BME concentration. The 4000 Level HCD Post-Survey included a total of 14 questions. In the survey, students were asked to define the terms "cultural competency" and "human-centered design."

3.8 Analytic Plan

Relationships were explored between HCD educational module modes of delivery, students' indication of the effectiveness of modules, students' ability to recognize HCDs after delivery of content, and students' indication of whether WPI's BME department should require implementation of HCD modules at each grade level. Survey participation and data collected from the Pre-Survey and the Post-Survey were used to evaluate whether the aims were met. The aims developed were as follows:

Aim i: To determine current levels and future need for a HCD curriculum within the BME department.

Aim ii: To gauge student opinions regarding the potential of a distributed HCD curriculum.

Aim iii: To evaluate student HCD knowledge according to the distributed HCD curriculum hierarchy after participating in one HCD module.

Aim iv: To determine the most efficient delivery method and identify the advantages of each delivery method.

IV. Results

4.1 Aim i: To determine current levels and future need for HCD curriculum within the BME department.

In order to determine if BME students believe HCDs are adequately covered by WPI's BME department, we asked students to report whether any previous BME courses they have taken delivered content on HCD (Table 1). Students were also asked to indicate how much prior knowledge of HCD they had and organized the data according to year of graduation (Figure 1). According to the survey data, 44.8% of BME students surveyed (n=165) had not received any content on HCD in their courses at WPI. Additionally, there was no statistical difference between graduation year and knowledge on HCDs.

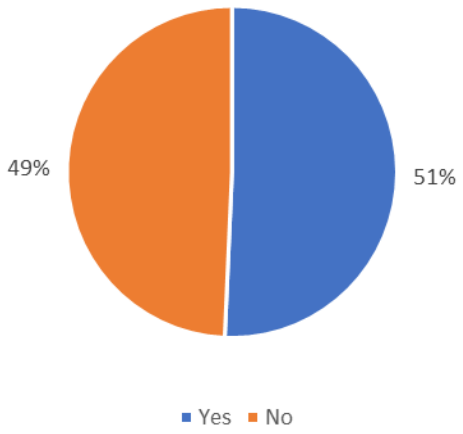

Figure 2. *Healthcare Disparities Education at Worcester Polytechnic Institute. Results from the pre-survey responses to the question, "Have any of your WPI classes delivered content on healthcare disparities?" There were a total of 165 responses of which 19 are marked as "missing" meaning students have skipped the question. A total of 146 students responded to this question. A total of 74 students said that they had not had any prior classes that covered healthcare disparities within their courses.*

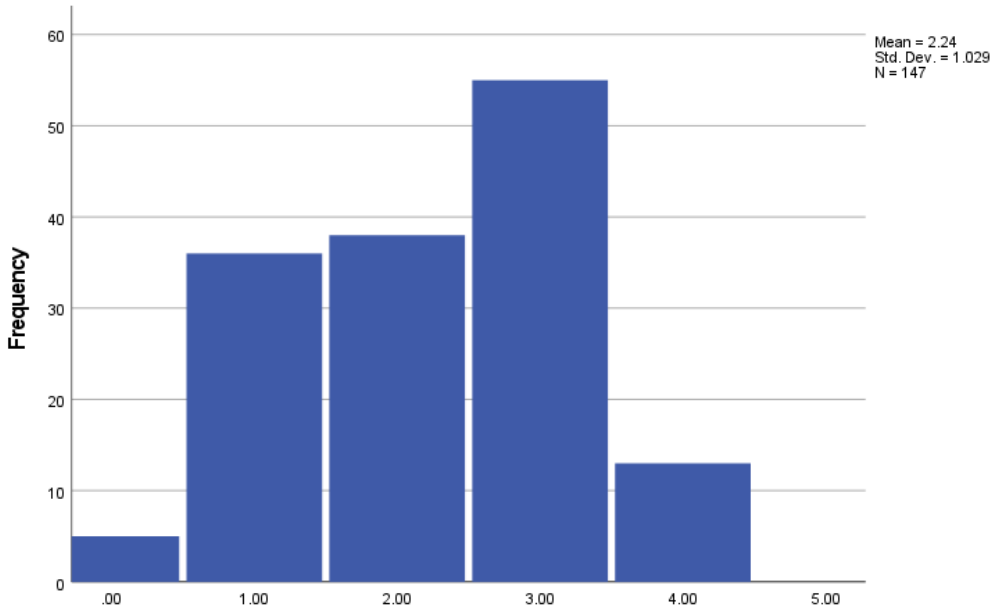

Figure 3. *Students' Rating on their Prior Knowledge on Healthcare Disparities. Results of students' responses to the pre-survey question, "How much prior knowledge about healthcare disparities do you have?" The students were given a scale from 0 to 5 as an answer selection with 0 indicating "none at all" and 5 indicating "an extensive amount." The mean value of the students' rating of their prior knowledge was 2.24, ranking the average knowledge on the*

healthcare disparities at a "moderate amount." No students indicated having "an extensive amount" of prior knowledge and few indicated "a lot" of prior healthcare disparity knowledge.

4.2 Aim ii: To gauge student opinions regarding the potential of a distributed HCD curriculum.

We asked students in the 2000, 3000, and 4000 level courses in the post-survey whether or not they believe HCD education is important and should be required by the BME department at WPI. Additionally, in order to determine whether BME students believed formal education on HCD could benefit them in future positions we asked the question:

> "If WPI would award Certificate of Healthcare Disparity Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your resume in the future when applying for jobs, research positions, or further degrees?"

Our group came up with a hypothetical award the BME department could give to students if they completed a HCD module at each course level during their time at WPI. The goal would be for students to use the certificate on job and education applications in order to enhance their application. According to the survey results, the majority of students indicated they think such a certificate would benefit their resume (Table 2).

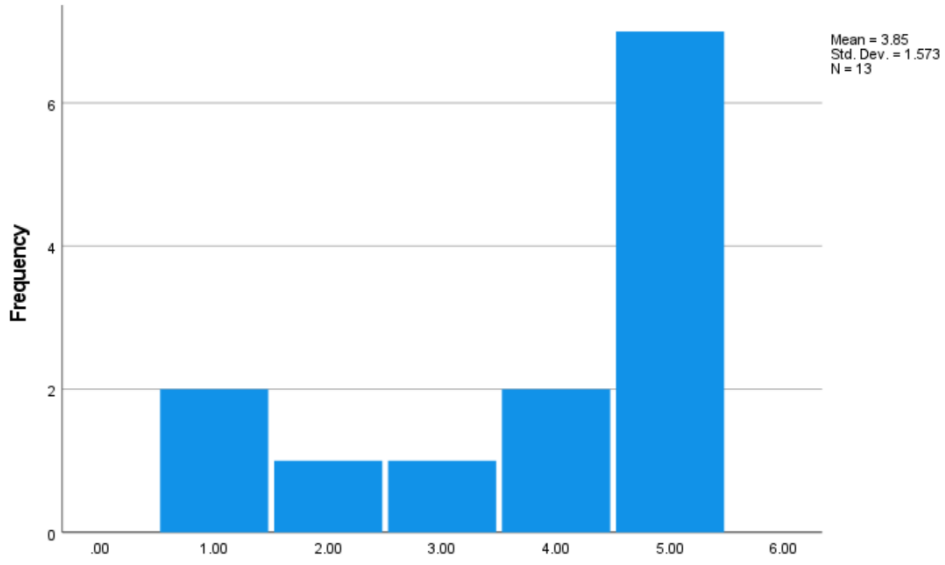

Figure 4. *2000-Level Course Students' Rating on Whether or Not a Healthcare Disparities Module Should be Required by the Biomedical Engineering Department Each Year. A histogram showing the results of students' responses in the 2000 level course post-survey to the question "Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?" The students ranked their agreement on a scale from zero to five. Zero indicating "strongly disagree" and five indicating "strongly agree." The mean ranking by the 13 students who answered the 2000 level course survey was 3.85 which is correlates to "somewhat agree" with making a HCD module per year.*

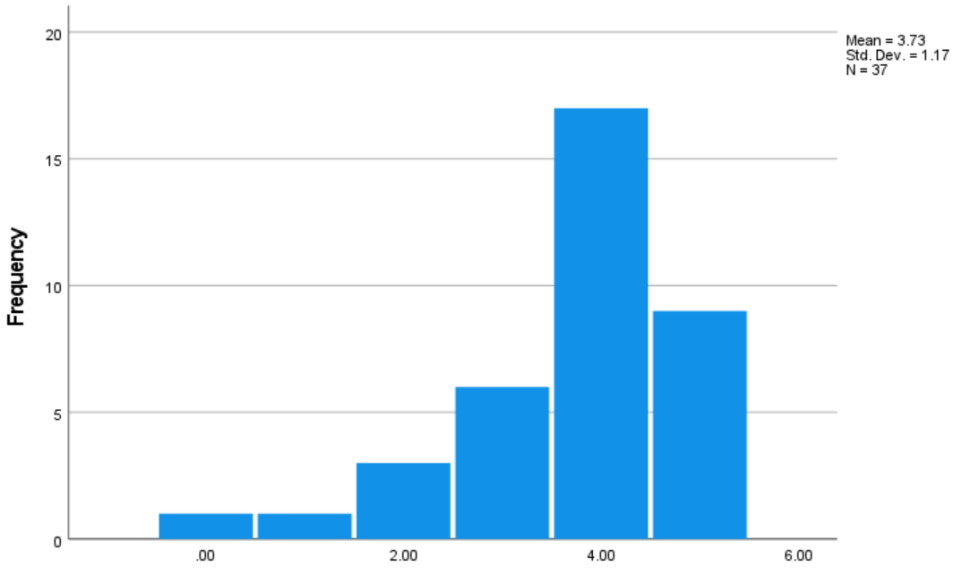

Figure 5. *3000-Level Course Student's Rating on Whether or Not a Healthcare Disparities Module Should be Required by the Biomedical Engineering Department Each Year. A histogram of the results of students' responses in the 3000 level course post-survey to the question "Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?" The ranking system is the same as within Figure 3. The mean ranking of agreement by the 37 students who answered this question was 3.73, which correlates to "somewhat agree" to making a HCD module required once per year.*

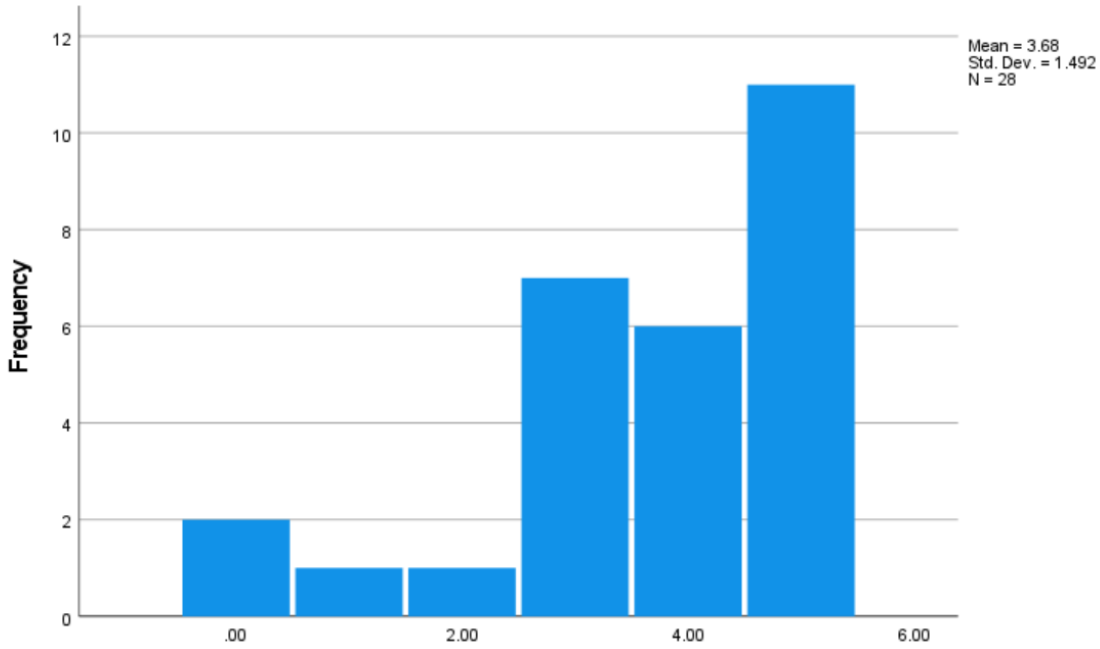

Figure 6. *4000-Level Course Student's Rating on Whether or Not a Healthcare Disparities Module Should be Required by the Biomedical Engineering Department Each Year. Histogram of the results of students' responses in the 4000 course level post-survey to the question "Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?" The ranking system is the same as within Figure 3 and 4. The mean ranking of agreement by the 28 students who answered this question in the survey was 3.68, which aligns with "somewhat agree" to making a HCD module required once per year.*

Table 2. *Desire for Healthcare Disparities Certificate Based on Student Responses at Each Course Level. Distribution of responses to the question "If WPI would award Certificate of Healthcare Disparities Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your*

resume in the future when applying for jobs, research positions, or further degrees?" Each course level post-survey showed a high interest and relevance towards a certificate in relation to healthcare disparities for students' future careers. More than three-fourths of each class level said yes to the question, the 1000 level course survey had an agreement rate of 100 percent.

Piloted Class Level	Yes to HCD Certificate & Beneficial to Resume	*n*
1000	100%	27
2000	79%	11
3000	87%	34
4000	90%	23

4.3 Aim iii: To evaluate student HCD knowledge according to the distributed HCD curriculum hierarchy after participating in one HCD module.

In the post-survey for each course level we asked the students, "Did the Healthcare Disparity Modules help you to improve your knowledge of healthcare disparities?" This question served to determine the overall efficacy of the HCD modules and whether they successfully increased a student's knowledge on the topic (Table 5). Additional questions in the post-survey were also asked to evaluate whether specific information delivered through the Course Level Overviews was retained by the students. Students at the 1000 course level were asked whether they were able to give a definition of HCDs, students at the 3000 level were asked whether they could provide an example of a HCD within each BME specialization, and students at the 4000 level were asked to provide definitions for "human-centered design" and "cultural competency " (Table 3).

Table 3. *Effectiveness of Modules Based on Students' Ability to Provide Crucial Definitions. Students' responses to questions that indicate the effectiveness of our modules. These questions varied based on course level. For example, in the 1000 course-level we asked if students would be able to give a definition, in their own words, of healthcare disparities. The student's available responses was "yes" or "no." If they replied "yes" they would be asked to give a written definition. From these two responses we were able to get the percentage of students who were able to answer key questions based on the course-level and provide a correct response. A majority of students indicated they were confident in their ability to give a definition or example and gave a proper written answer.*

Class Course Level	**HCD Definition/Topic**	**Able to give definition/example**	**n**
1000	HCD Definition	96%	26
2000	N/A	N/A	N/A
3000	Biomaterials Example	93%	37
	Biomechanics Example	85%	34
	Bioinstrumentation Example	63%	25
4000	Human-Centered Design	96%	27
	Cultural Competency	96%	27

Table 4. *Students' Ranking on the Importance of Healthcare Disparities Education for their Intended Future Career at Each Course Level. Average ratings from each course-level post-survey to the question "How important do you think it is to address healthcare disparities in*

your intended future career?" The scale for this question was from zero to five, with five correlating to "very important." Every course level indicated that they viewed healthcare disparities to be between "somewhat important" to "very important," by having a mean rating between four and five.

Class Course-Level	Mean Rating (Scale from 0 to 5)	STDEV	N
1000	4.41	0.797	27
2000	4.56	0.756	14
3000	4.59	0.715	39
4000	4.53	0.730	30

Table 5. *Students' Perceived Knowledge on Healthcare Disparities After Using Our Modules. Students' responses to the question "Did the Healthcare Disparities Module help you to improve your knowledge of healthcare disparities?" This question was asked in the post-survey at each course-level. The scale was from zero to five, where five indicated "definitely yes." All course levels viewed that the modules did improve their perceived knowledge on healthcare disparities.*

Class Course-Level	Mean Rating (Scale from 0 to 5)	STDEV	N
1000	4.33	0.820	27
2000	4.36	0.633	14
3000	4.15	0.933	39
4000	4.00	0.743	30

4.4 Aim iv: To determine the most efficient delivery method and identify the advantages of each delivery method.

In order to analyze the overall participation level of the students, the number of responses for the provided post- and pre-surveys was analyzed in the form of the 100% stacked columns (Figure

7). According to the performed analysis, 39.1% (*n*=203) of all participants responded to the pre-survey, and 27.4% (*n*=142) responded post-survey.

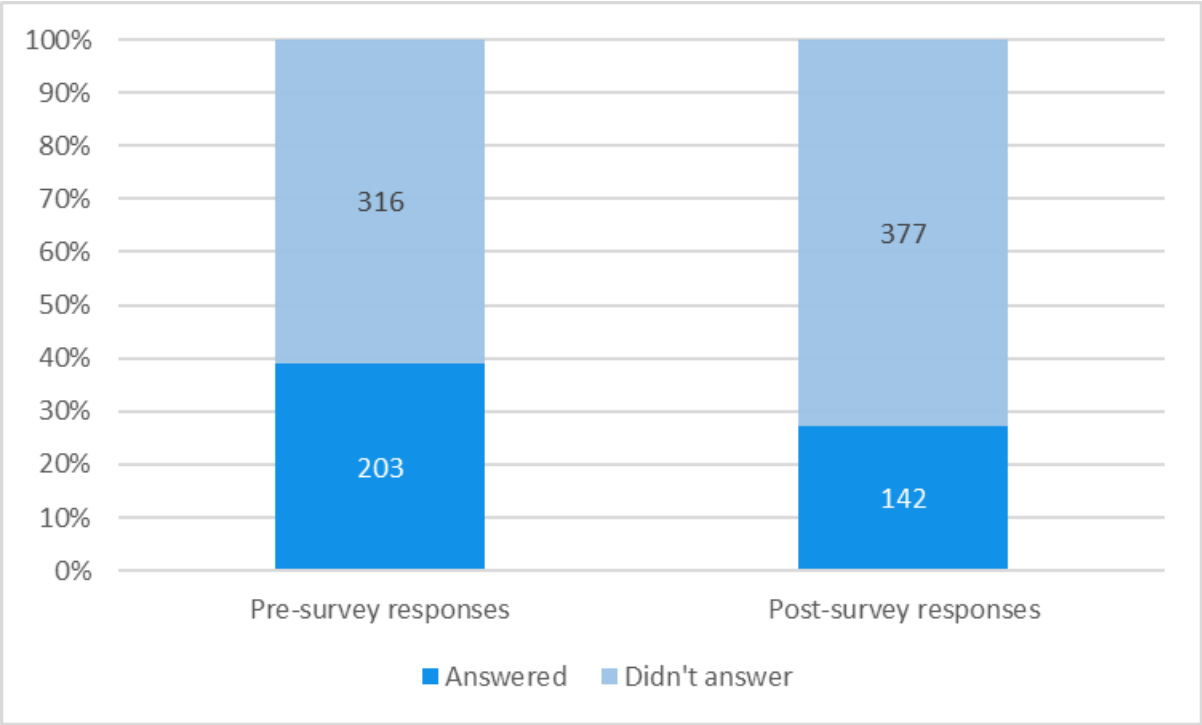

Figure 7. *Response rates for pre- and post-surveys showing if students responded or did not respond to survey questions. Analysis of the number of responses for the provided pre- and post-surveys. There were a total of 519 participants in all the classes where we were able to perform our pilot tests. A total of 203 students responded pre-survey. A total of 142 responded post-survey.*

Since the post-survey response rates are more reflective of student participation, it was decided to concentrate on post-survey response rate analyses. Figure 8 demonstrates the post-survey response rate in the format of 100% stacked horizontal bars for each of the levels where we were able to test our pilots. Based on the performed analysis, we evaluated that 41.3% (*n*=52) of students of 4000-level responded post-survey. All the other levels demonstrated lower rates in

terms of filling out the post-module questionnaire. Only 22.6% (*n*=45) of students of 3000-level responded post-survey, 26.3% (*n*=15) of students of 2000-level , and 21.9% (*n*=30) of students of 1000-level.

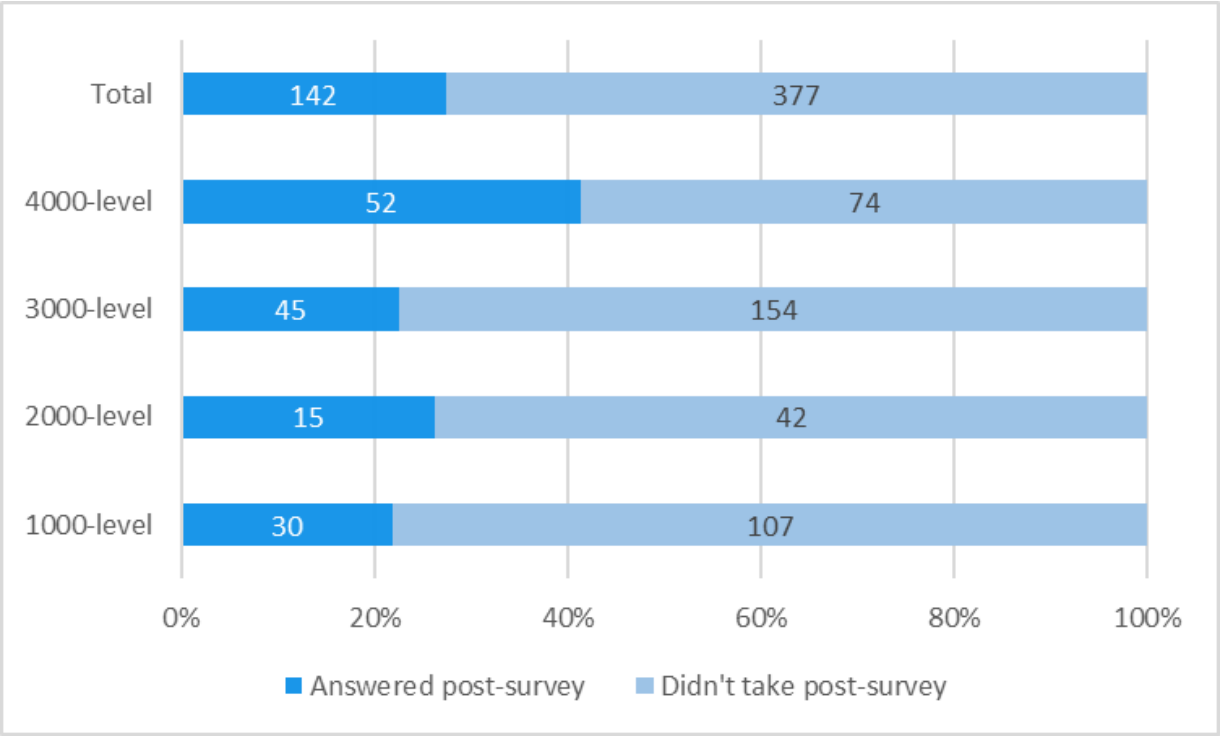

Figure 8. *Post-survey response rates for the students of different course levels showing if students did or did not respond to survey questions. Analysis of the number of responses for the post-surveys. There were a total of 142 post-survey responses from all levels where we performed our modules' pilots. We received 52 post-survey responses from students of 4000-level, 45 responses from students of 3000-level, 15 responses from students of 2000-level, and 30 responses from students of 1000-level.*

Another goal was to understand the number of students educated using each of the delivery methods as well as their rates of post-survey responses. Overall, there was a total of 519

students enrolled in all the classes where we were able to pilot our modules. 53.6% (*n*=278) of them were enrolled in the classes where our modules were delivered in the hybrid format, while 46.6% (*n*=241) were in the classes where our modules were piloted in the asynchronous mode. In order to distinguish the students who completed our modules in asynchronous vs. hybrid modes, it was manually determined which responses were obtained from which class based on the dates when each individual completed the post-survey. After we assigned each of the responses to the individual class and added up all of the obtained values. Out of all the students who were enrolled in the classes where our modules were taught in the hybrid mode, the post-survey was completed by 34.2% (*n*=95) of the students. In the meantime, out of 241 students who were enrolled in the classes where our modules were given in the asynchronous mode, the post-survey was completed only by 19.5% (*n*=47) of the students.

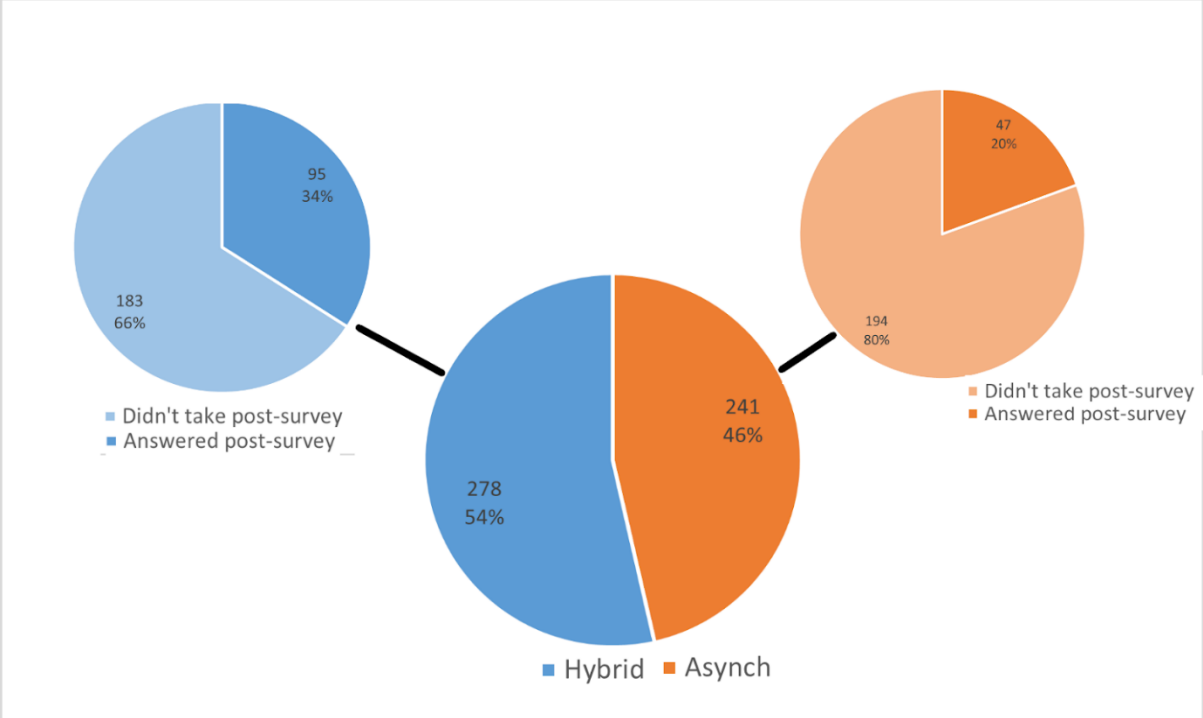

Figure 9. *Amount of students for each of the delivery modes with a specific post-survey*

responses ratio for each of the provided delivery modes. Analysis of the number of students receiving our modules in a hybrid vs. asynchronous mode with additional evaluation of the post-survey response rates for each of the delivery modes. Out of a total of 519 students enrolled in all the classes where we were able to perform our pilot tests, 278 students were supposed to receive our modules in hybrid format, while 241 were expected to receive them asynchronously. Out of 278 students who were supposed to learn our modules in hybrid mode, 95 students responded to the post-survey. Out of 241 students who were supposed to receive our modules in asynchronous mode, 47 students responded to the post-survey.

In order to understand the overall opinion of the students on our modules, every post-survey contained the question: "did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?" We were able to analyze the responses of the students who were receiving our HCD modules in the different modes and represent them in the form of the pie charts (Figures 10 and 11). There were 47 students who were taking our modules asynchronously and took a post-survey, 49% of them (n=23) rated the helpfulness of our modules with the value of 4 which can be interpreted as "Probably yes". Similarly, out of 95 hybrid students who responded post-survey, 44% (n=42) indicated their satisfaction with our modules with a value of "4."

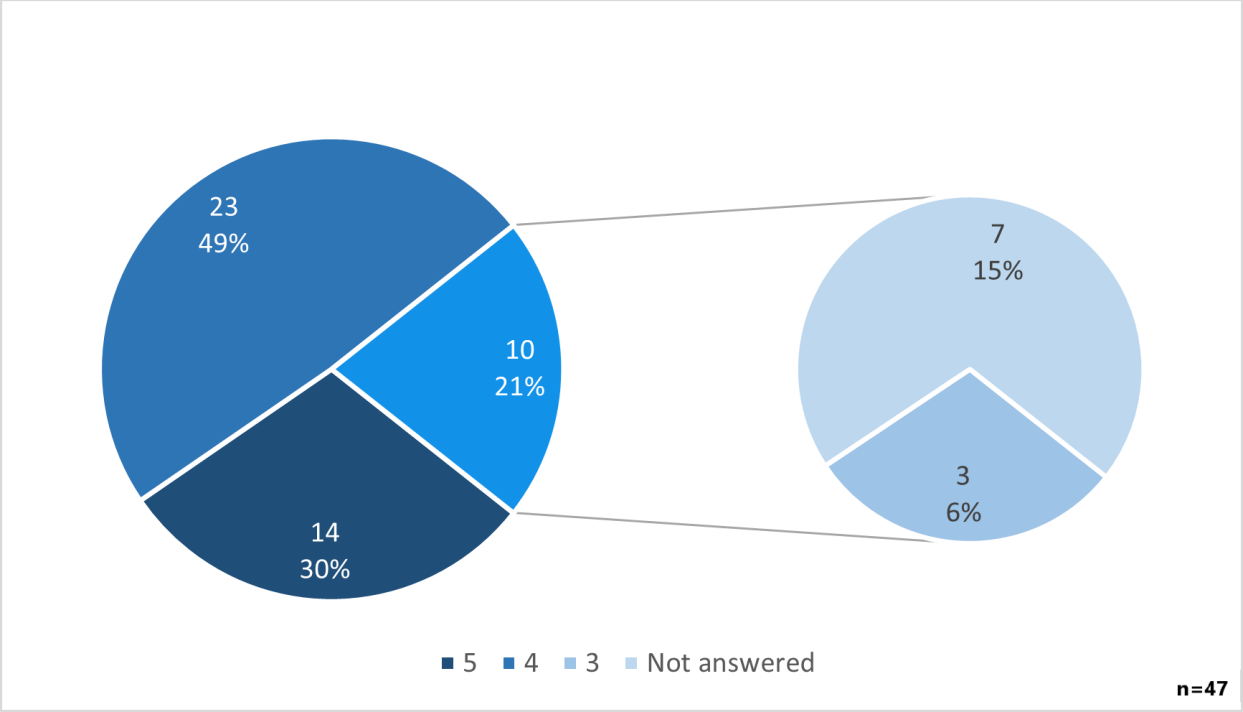

Figure 10. *Asynchronous Student's Rating on Whether Our Modules Helped Them to Improve Their Knowledge on Healthcare Disparities. A pie chart showing the responses to the post-survey question "Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?" from the students who were doing our modules in asynchronous mode. The chart on the left demonstrates the rate of responses of the values "4", "5", and "3 and lower". The one on the right breaks down the percentages of the values "3 and lower". The students ranked their agreement on a scale from zero to five, where zero indicated "Definitely not" and five indicated "Definitely yes". The mean answer from 47 students of the asynchronous delivery mode was found to be 4.01 which correlates to "Probably yes".*

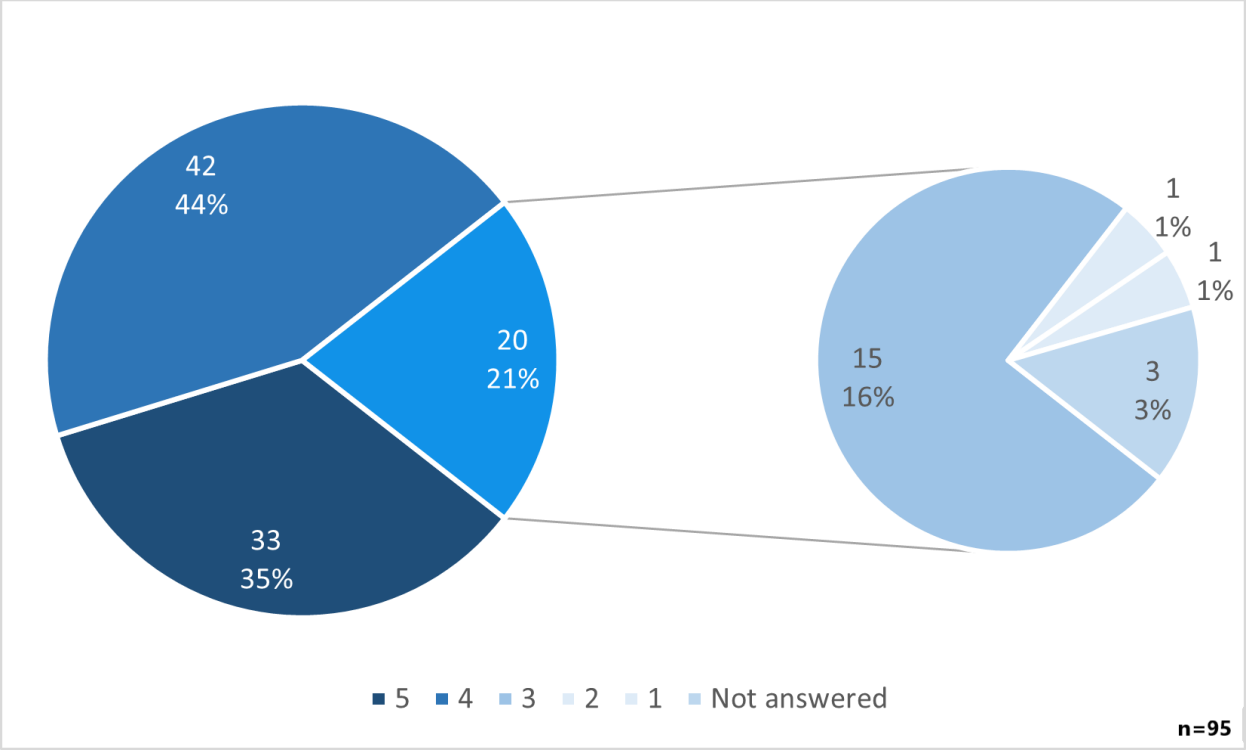

Figure 11. *Hybrid Student's Rating on Whether Our Modules Helped Them to Improve Their Knowledge on Healthcare Disparities. A pie chart showing the responses to the post-survey question "Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?" from the students who were doing our modules in hybrid mode. The organization of the pie charts, as well as the answers ranking system was the same as described in Figure 10. The mean value of the answers from 95 students of the hybrid delivery mode was found to be 3.64 which correlates between "Might or might not" and "Probably yes".*

Table 6. *Table Displaying Statistical analysis of Figures 10 and 11. Average ratings from students who used different delivery methods to the question "Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?". Both asynchronous and hybrid students indicated that they find our HCD modules helpful. Their response to the*

mentioned question fluctuated between "Might or might not" to "Probably yes" with the mean values of 3.64 and 4.01, respectively.

Method of delivery	Mean Rating (Scale from 0 to 5)	STDEV	N
Asynchronous	3.64	1.62	47
Hybrid	4.01	1.07	95

We were able to test our module for students of 3000-level classes in both asynchronous and hybrid formats. It allowed us to compare the efficiency of each delivery method by analyzing if the students were able to confirm the knowledge they gained from our modules. The 3000-level post-survey contained the following three questions:

"Can you name a particular healthcare disparity that could arise within biomaterials?"

"Can you name a particular healthcare disparity that could arise within biomechanics?"

"Can you name a particular healthcare disparity that could arise within bioinstrumentation?"

The students could respond with "Yes/No" answer options. Out of 17 students who were receiving our modules for 3000-level in asynchronous mode, 70.6% (*n*=12) indicated that they are able to name a particle HCD within Biomaterials specialization; 64.7% (*n*=11) were able to name a particle HCD within Biomechanics specialization; and 47.0% (*n*=8) - within Bioinstrumentation specialization. Similarly, out of 28 hybrid students of 3000-level who responded post-survey, 44% (*n*=42) indicated that they can name a particular HCD within the Biomaterials, Biomechanics, Bioinstrumentation specializations in 89.3% (*n*=25), 89.3% (*n*=25), 60.7% (*n*=17) cases, respectively (Figures 12 and 13).

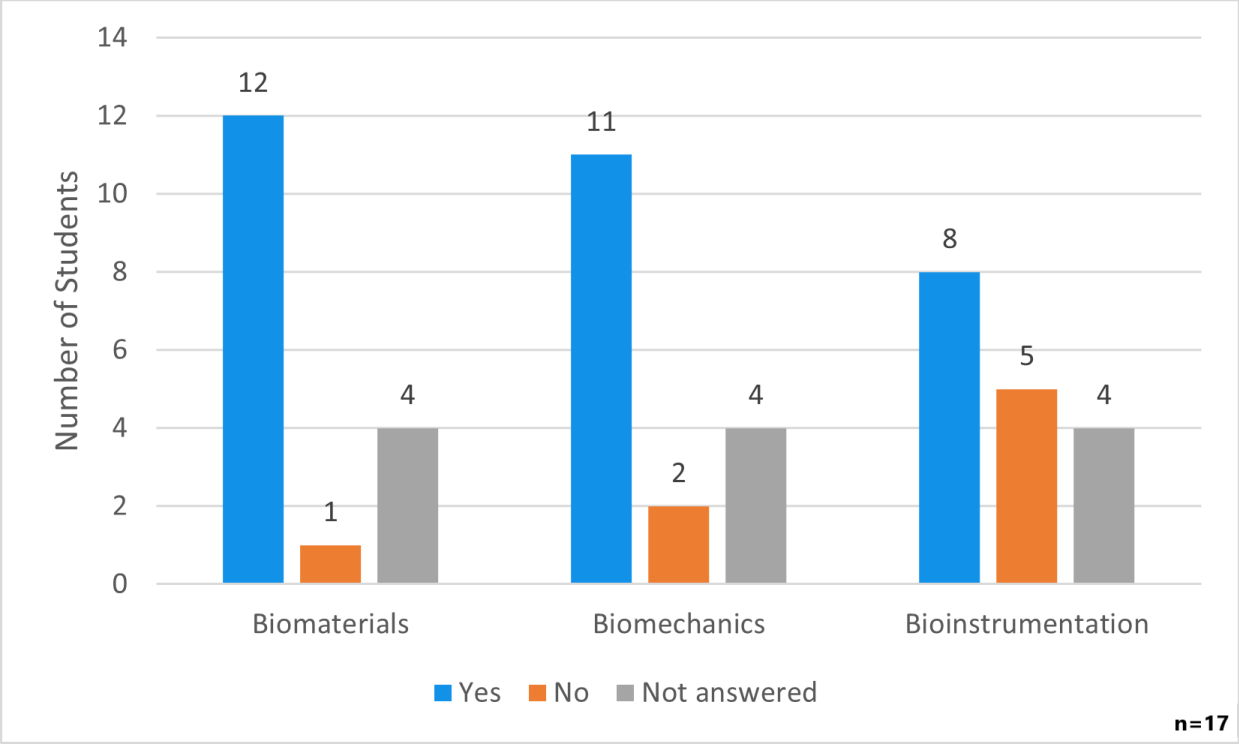

Figure 12. *Asynchronous Student's Rating on Whether They Can Name a Particular Healthcare Disparities Example after Getting Familiar with Our Modules. "Yes/no" responses ratio of 3000-level students using our modules in asynchronous mode answering the question "Can you name a particular HCD that could arise within biomaterials/biomechanics/bioinstrumentation?".*

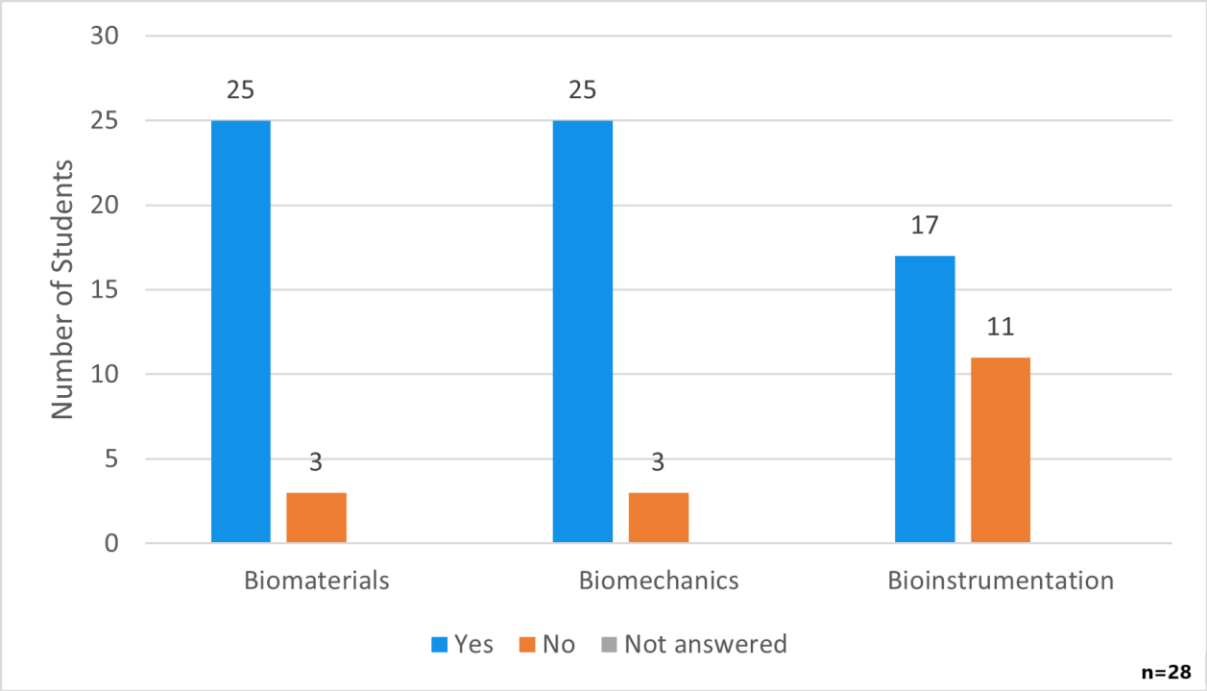

Figure 13. *Hybrid student's rating on whether they can name a particular healthcare disparities example after getting familiar with our modules."Yes/no" responses ratio of 3000-level students using our modules in hybrid mode answering the question "Can you name a particular HCD that could arise within biomaterials/biomechanics/bioinstrumentation?".*

A chi-square test of independence revealed that the ability to answer the question rates (yes/no) did not differ significantly by delivery mode (asynchronous or hybrid).

Table 7.

Chi-Square Test and p- Values Found for Each of the BME Specializations.

Specialization	$\chi 2(1)$	p
Biomaterials	0.09	0.76
Biomechanics	0.18	0.67
Bioinstrumentation	0.0025	0.96

However, even though some of the students indicated that they could name a particular HCD in some of the BME disciplines, they did not give an explicit response when they were asked to write an example in the provided textbox.

Table 8.

Analysis of the Students Who Indicated their Ability to Name a Particular HCD but Left the Provided Textbox Empty or Gave Unclear Answer. Number of students who did not give an explicit example of the disparities for each of the BME specializations. Each cell contains a set of two numbers (where the first numeric indicates the number of students who did not give a valuable answer and the numeric in the brackets shows the percentage of that amount from the total amount of students of that category who indicated that they can provide an example of the Healthcare Disparities) or a N/A sign (which means that all students in that category were able to give an explicit meaningful answer).

Delivery model	Biomaterials	Biomechanics	Bioinstrumentation
Asynchronous	N/A	1 (9%)	N/A
Hybrid	3 (12%)	4 (16%)	4 (23.5%)

V. Discussion

For this IQP we determined a scaffolded approach to education on HCD is a practicable method for standardizing the HCD education within the BME department at WPI. We successfully created HCD modules for each course level and piloted them within five courses, using two modes of delivery— asynchronous and in-person. We developed three aims to assess

the current HCD education in the BME department, students' opinions on HCD education, and whether the modules were able to increase their knowledge of HCD.

Our first aim was to determine the current levels and future need for a HCD curriculum within the BME department at WPI. Our findings support that the WPI BME undergraduate students are not receiving enough education on HCD. The pre-survey revealed only 51% of students surveyed (n =146) indicated their BME classes delivered content on WPI. Similarly, students indicated knowing only a "moderate amount" of HCD knowledge. These results were expected due to the overall trend of HCD awareness only minimally increasing in the United States (Benz, 2011) and from findings in last year's IQP, which established the need for a HCD education in WPI (Cordner, 2021). Additionally, it was expected for students to indicate they had some prior knowledge on HCD, as the previous IQP had piloted HCD education within their courses. Overall, these results support there is a distinct need for a structured, scaffolded HCD curriculum to be established within the BME department.

Our second aim was to gauge student opinions regarding the potential of a distributed HCD curriculum. Results revealed students in the BME department not only believe the BME department should require HCD education, but that it could benefit them in the future. More than half of students in the 2000, 3000, and 4000 level courses indicated they think the BME department should require HCD knowledge and almost all students in each course level indicated they think it could benefit their future resumes (Table 2). These results align with the BME professors' responses to the BME professor survey climate that indicated they believe HCD education is important and that they would like to incorporate such education within their courses.

Our third aim was to evaluate student HCD knowledge according to the distributed HCD curriculum hierarchy after participation in one HCD module. Based on the survey results, the HCD modules were shown to successfully increase the students' knowledge on HCD. The majority of students who took part in our modules indicated the modules had helped, with mean values at each course level corresponding to "definitely yes" (Table 5). Not only did students indicate that the modules helped them to improve their knowledge, but students showed they were able to recall learned information from the HCD modules. These results coincide with results found in other pilot studies within BME departments at other institutions, namely the results the BME department at The City College of New York (CCNY). While our study was only conducted within a seven-week term at WPI versus the CCNY study which was done over a four-year period, it is clear didactic modules developed for each course level are effective for increasing students' knowledge in HCD.

Aim iv was to determine the most efficient delivery method and recognize the advantages of one delivery mode over another. We were able to perform a separate analysis of the overall level of satisfaction of students who used different delivery methods while learning the developed material. This analysis can give an overall understanding if the students who used our modules asynchronously, i.e. on their own, had encountered a worse experience while using the prepared HCD material. With unpaired t-test statistical analysis, it was found that the difference in the responses from the students who used our modules asynchronously vs. in the hybrid formats is not statistically significantly different (Figures 10 and 11). Students who used our modules in the asynchronous format had a similar outcome to those who participated in the in-

class discussions. Both test groups indicated an increase in perceived knowledge on healthcare disparities after using our modules.

In order to determine the efficiency of the different delivery methods in terms of the learning outcomes, we also tried to investigate if there can be found any significant difference in the abilities of students to confirm the knowledge they gained from our modules (Figures 12 and 13). Based on the performed chi-square test of independence, it was determined that the delivery method had no statistically significant effect on students' willingness to answer the question relevant to the knowledge they gained from the provided HCD modules.

Overall, we were not able to determine if hybrid or asynchronous delivery modes have any advantages over each other in terms of the educational outcomes. This conclusion is also confirmed by similar researches performed in the past (Goggins, 2016; Thomas, 2013).

Our group did not originally set up the study to determine efficacy of the different delivery modes. However, based on post-survey response rates, we may assume that the overall level of engagement is lower among students who used the asynchronous delivery technique rather than the hybrid method. Students who used the asynchronous style of delivery had lower post-survey response rates than those who used the hybrid mode of delivery (Figure 9). This could indicate that asynchronous students are less engaged in terms of submitting the post-module assignments. Based on the performed analysis, it can be concluded that instructors who might wish to use our HCD education modules in combination with a post-module evaluation might face some difficulties attracting the students to participate asynchronously. If professors were to implement these modules asynchronously it might be more challenging to get students to engage. Therefore, the evaluation would most likely need to be graded or have some sort of incentive for completion.

5.1 Limitations

Although the results supported our aims, limitations existed in the study. One major limitation was the time constraints the project group faced due to the short 7-week term system at WPI. For the IQP specifically, this made it difficult to recruit and coordinate with professors who could pilot our HCD modules within their courses. Professors found it difficult to find class time in their course schedules to accommodate for delivery of HCD content. For this reason, we were not able to meet our goal to pilot our HCD modules in at least two classes per course level. Another drawback to the short term system was inconsistency with how the modules were delivered as a result of trying to accommodate the professors' course schedules. The goal was to have professors dedicate either a full class period (50 minutes) or half a class period (25 minutes) to deliver a class discussion on HCDs. Not every professor was able to give up class time to pilot the IQP, making two classes have content delivered virtually. Additionally, due to the fact that the examination of the efficiency method was a secondary goal of this IQP, pre- and post-surveys were not designed to compare the modes of delivery, therefore qualitative data was not collected to be able to determine which mode of delivery was best for delivery of the HCD curriculum. The described above manual method of analysis of the used delivery modes used by students cannot be called a precise way to perform the statistical evaluations.

Additionally, student survey response rates to the pre-and-post survey were below what was expected based on the numbers of students registered per course and responses on the post-surveys were less than the number of responses to the pre-survey. Even though most professors offered extra credit for completion of the surveys and time was given to students during the in-class HCD module delivery, students still did not respond to the surveys. This could have

affected the results from our survey, as it is possible only the students who believe HCD education is important and were engaged in the HCD content answered the surveys.

5.2 Future Recommendations

Clear evidence was established by this IQP that the BME department at WPI currently lacks an established HCD curriculum. With ABET requirements calling for students to gain an ability to recognize ethical responsibilities in their work and to demonstrate an ability to design products that consider "public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" (*Criteria for Accrediting Engineering Programs, 2021 – 2022 | ABET*, 2022), it is crucial for the BME department to establish a standardized requirement for students to receive education on ethics and HCD. In addition to the ABET requirement for engineering students to learn about ethical considerations and the implications of their products on society, ABET is proposing to incorporate new Diversity, Equity, and Inclusion (DEI) standards, including:

> *c. A professional education component that is consistent with the institution's mission and the program educational objectives and promotes diversity, equity, and inclusion awareness for career success* (*Accreditation Changes ABET*, 2022).

This new DEI standard aligns with WPI's "innovation" value and mission that states, "We act ethically, recognizing how innovation affects different populations" (Mission & Values, 2022). Both the ABET requirements and WPI's missions and values display the need for the BME department to move towards improving their HCD education through an established, scaffolded curriculum alongside the current BME curriculum.

Given that students' ability to recognize HCDs increased across all course levels and in each course piloted after only one session of HCD educational content, both in-person and online, our group proposes establishing a required comprehensive HCD curriculum in the BME department at WPI. Such a curriculum should be integrated within courses in the BME department at each grade level and should include a HCD Course Level Overview, case studies pertinent to the given course a student is in, and a HCD presentation based on the specific course a student is taking. According to the literature, a one hour module each year would provide students with a sufficient amount of knowledge on HCD, showing that the BME department should require students to partake in a HCD module at least once a year.

The HCD Course Level Overview would ensure that students in a given course level will be receiving consistent knowledge appropriate for their grade level, regardless of the course they are in, thus standardizing the curriculum. Case studies were shown to engage students in the content during delivery and are shown to be an effective way of delivering content tailored to specific courses (Bradford, 2009). They should be chosen by the professor of the course, as the professor is an expert in the course they are instructing and could best identify and discuss examples of HCD to their students. Additionally, the professors should work to develop a HCD presentation specific to their course to present to their students and to facilitate a discussion in HCD during class time.

In order to accomplish this, the BME department at WPI would need to make it a requirement for professors to deliver a HCD module during their course and would need to work with the professors to develop a course of action and materials that would sustain such a curriculum. A major obstacle this IQP faced was convincing professors to pilot our HCD content in their course and to schedule a time with them to do so. As a result of the seven-week term

system at WPI and the short breaks between each term, by the time our IQP requested a professor to pilot HCD content in their course, their course schedule had already been established making it an extreme challenge for them to accommodate time to deliver HCD content. Making delivery of one HCD module in each course a requirement would allow for professors to plan ahead and adjust their course schedules in order to accommodate one HCD module. Additionally, this would eliminate the uncertainty that a professor may or may not deliver the content and would eliminate the time that was dedicated to meeting with professors to schedule a time for delivery of HCD content.

Professors in the BME department would also need to develop HCD materials such as case studies and presentation slides specifically tailored to each BME course. Doing so would allow students in each course to not only better engage with the HCD module being taught, but to receive a new HCD lesson in every course they take. This would also allow the students to apply their learned HCD knowledge from previous course level HCD modules and the course level specific HCD overview to different specializations and scenarios. In addition to having BME professors developing HCD materials, our group recommends that the HCD content is delivered by the professor in the course themselves. Delivery of the content by the professors would ensure the content is being taught by an expert in the given course. This would help to better facilitate discussions with the students and create dialogue during the discussions. Professors could better guide the discussions and provide relevant examples for the students based on their expert knowledge and personal experiences in their profession. This would also eliminate the need to recruit a new team or presenter to deliver the HCD modules to each BME course each year. Having the professors develop the HCD materials to be used for each course and having the professors deliver the content would allow the HCD curriculum to be sustainable.

It is also recommended by our IQP group that a guide is developed to help MQP groups write the "ethical considerations" section in their MQP final reports. As it stands, MQP advisors report MQP groups struggle with writing this section. This could be a result of the lack of a standardized education on ethics and HCD in the BME department. The guide should include a summary of the HCD Course Level Overviews developed by our IQP group, examples of successful ethical consideration sections from previous MQPs, and questions the group could answer in order to guide their writing. Example questions could include: (1) Who is affected by our MQP product? (2) Would all individuals benefit from our MQP product? (3) Could everyone afford and access our MQP product?

Future IQP groups should investigate a formal proposal for inclusion of a comprehensive HCD curriculum in the BME department and should work with the department to make it a requirement for students to engage in such a curriculum during each course level while at WPI. The entire BME department should come together on such a curriculum to develop a standardized and sustainable method for delivery of the education and to develop content that can be continuously used by professors in the future. Without making an established curriculum, developing content to be used each year, and making the curriculum required, HCD education in the BME department will continue to be inconsistent and unsuccessful in educating all students on the topic.

VI. Conclusion

Clear evidence was established by this IQP that the BME department at WPI currently lacks an established HCD curriculum. With ABET requirements calling for students to gain an ability to recognize ethical responsibilities in their work, it is crucial for the BME department to

establish a standardized requirement for students to receive education on ethics and HCD. Our IQP developed and piloted a hierarchical HCD curriculum for the BME department at WPI based on the educational scaffolding of Bloomberg's Model. Based on results from this project, it is clear that the BME department should work to develop and incorporate a comprehensive HCD curriculum based on the curriculum developed in this IQP. This would not only fulfill ABET's requirements and WPI's missions and values but would ultimately ensure WPI is educating future engineers to create with the ability to recognize and prevent HCDs in the future. Continuously having IQP groups investigate education on HCD in the BME department is not sustainable, nor does it create a long-lasting impact on students. We believe the department needs to act on the data presented not only in this year's IQP, but previous IQPs, displaying the need and desire for better delivery of HCD content to students. With this IQP, we hoped to create a baseline for the department to initiate a plan to officially propose a required HCD curriculum for BME students.

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Appendix

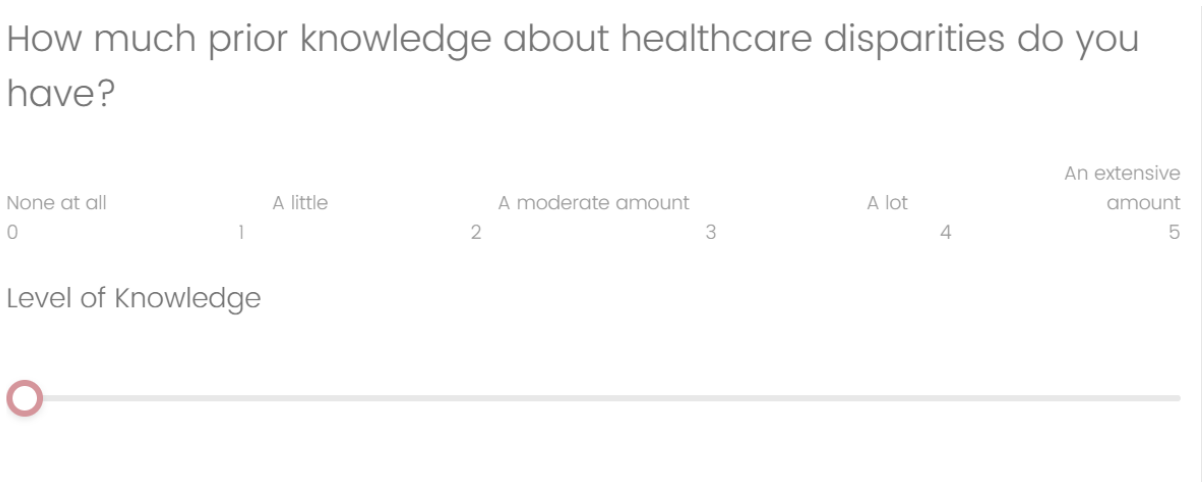
Student Survey

Pre-Survey

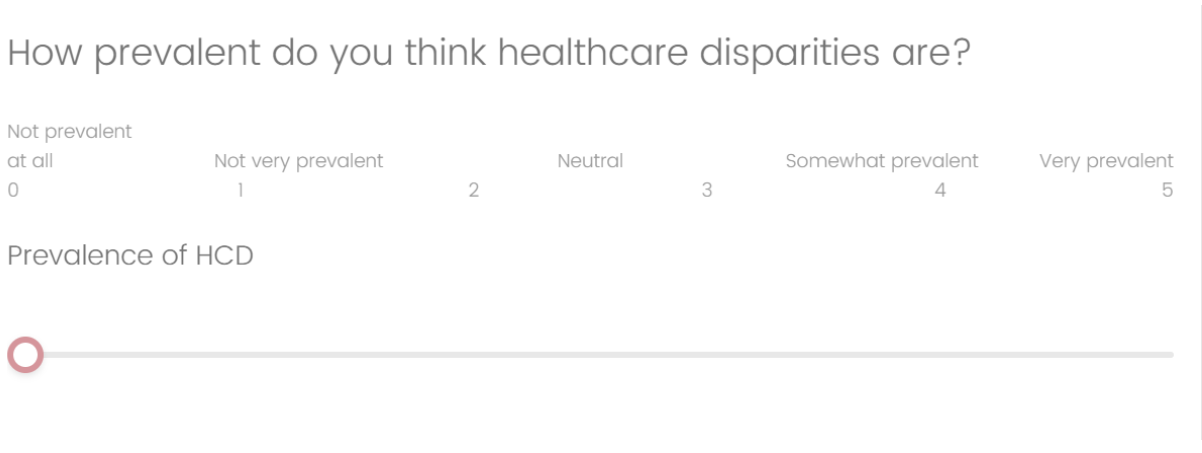
Baseline examination of students prior knowledge of healthcare disparities

Baseline Questions About HCD

1.



2.



3.

How important do you think it is to address healthcare disparities in your intended future profession?

Not at all important	Slightly important	Moderately important	Very important	Extremely important
0	1	2	3	4	5

Importance of HCD in your future profession

4.

Have any of your WPI classes delivered content on healthcare disparities?

- ○ Yes
- ○ No

Demographic

5.

What is your anticipated year of graduation?

- ○ 2022
- ○ 2023
- ○ 2024
- ○ 2025
- ○ Other

6.

Please select the option below that most closely matches your gender identity.

- ○ Male
- ○ Female
- ○ Non-binary
- ○ Prefer not to respond

7.

Please select the option below that reflects the racial/ethnic group with which you most closely identify.

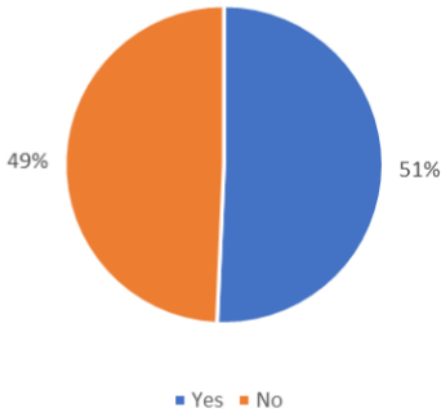
- ☐ White (e.g., European descent)
- ☐ Black (e.g., African, Afro-Caribbean, etc.)
- ☐ Hispanic/Latinx
- ☐ Asian or AAPI
- ☐ Mixed
- ☐ Other

Appendix A: *Pre-Survey distributed to students.*

Results of Pre-Survey

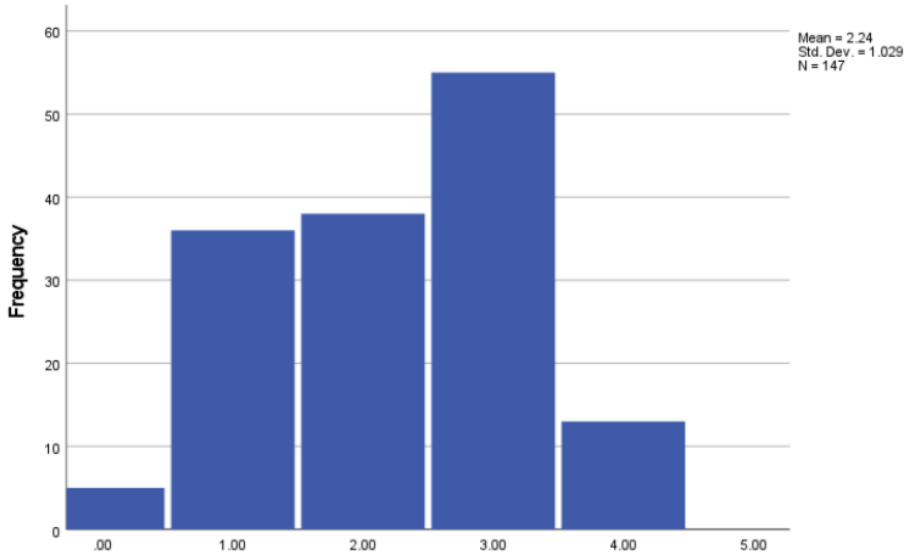
1.

Have any of your WPI classes delivered content on healthcare disparities?



2.

How much prior knowledge about healthcare disparities do you have?



Appendix B: *Results of the Pre-Survey.*

Student Survey
1000 Level Course Post-Survey examination of students' knowledge of healthcare disparities prior to delivery of modules
Module Overview
1.

Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?

Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
1	2	3 3	4	5

Scale of utility

2.

How important do you think it is to address healthcare disparities in your intended future career?

Not important	Somewhat unimportant	Neutral	Somewhat important	Very important
0	1	2 3	4	5

Importance of HCD in your future career

3.

If WPI were to award a Certificate of Healthcare Disparity Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your resume in the future when applying for jobs, research positions, or further degrees?

- ○ Yes
- ○ No

HCD Overview
4. Do you think you can give a definition of Healthcare Disparities? ◯ Yes ◯ No **5.** Can you provide one example of a Healthcare Disparity currently affecting individuals in the United States? ◯ Yes ◯ No

Appendix B: *1000-Level Course Post-Survey delivered to students after modules delivered in BME 1004.*

Results of Pre-Survey for 1000-Level Courses
1. Have any of your WPI classes delivered content on healthcare disparities?

2. *How much prior knowledge about healthcare disparities do you have?*

Appendix C: *Results of 1000-Level Course Post-Survey.*

Student Survey
2000-Level Course Post-Survey
HCD Overview
1.      **2.**

How important do you think it is to address healthcare disparities in your intended future career?

Not important 0 | Somewhat unimportant 1 | 2 | Neutral 3 | Somewhat important 4 | Very important 5

Importance of HCD in your future career

3.

If WPI were to award a Certificate of Healthcare Disparity Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your resume in the future when applying for jobs, research positions, or further degrees?

- ◯ Yes
- ◯ No

4.

Do you think the Healthcare Disparity module helped you to understand that certain populations are often left out of design considerations?

0 | 1 | 2 | 3 | 4 | 5

Helpfulness of the modules in terms of the design considerations

5.

Do you think the Healthcare Disparity module convinced you that the field of Biomedical Engineering (BME) and the field of healthcare depend on and affect each other?

- ◯ Yes
- ◯ No

6.

Do you think the Healthcare Disparity module convinced you that it is important for Biomedical Engineers to understand and learn about healthcare disparities?

Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
0	1	2 3	4	5

Persuasiveness of the module

7.

Do you feel more confident in recognizing potential healthcare disparities in your future career or research?

- ◯ Yes
- ◯ No

Module Overview

8.

How engaging were the Course Level Overview slides?

0 1 2 3 4 5

Level of engagement

9.

How did you find the organization of the Canvas page?

0 1 2 3 4 5

Level of organization

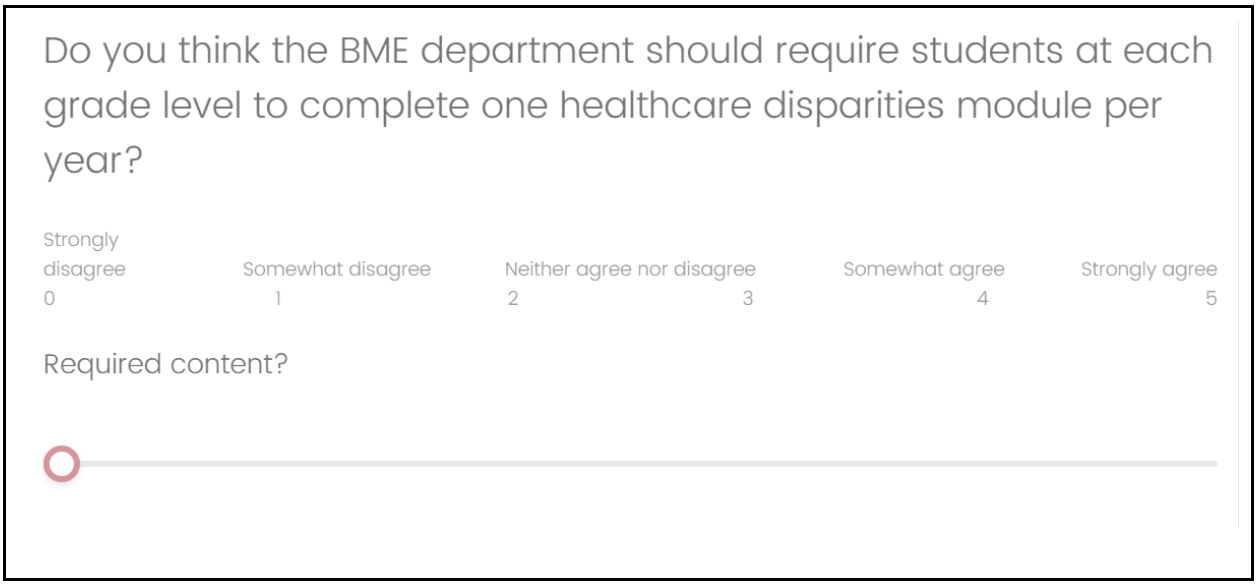
10.

Did the assignment help you to further your understanding of healthcare disparities and apply your knowledge?

0 1 2 3 4 5

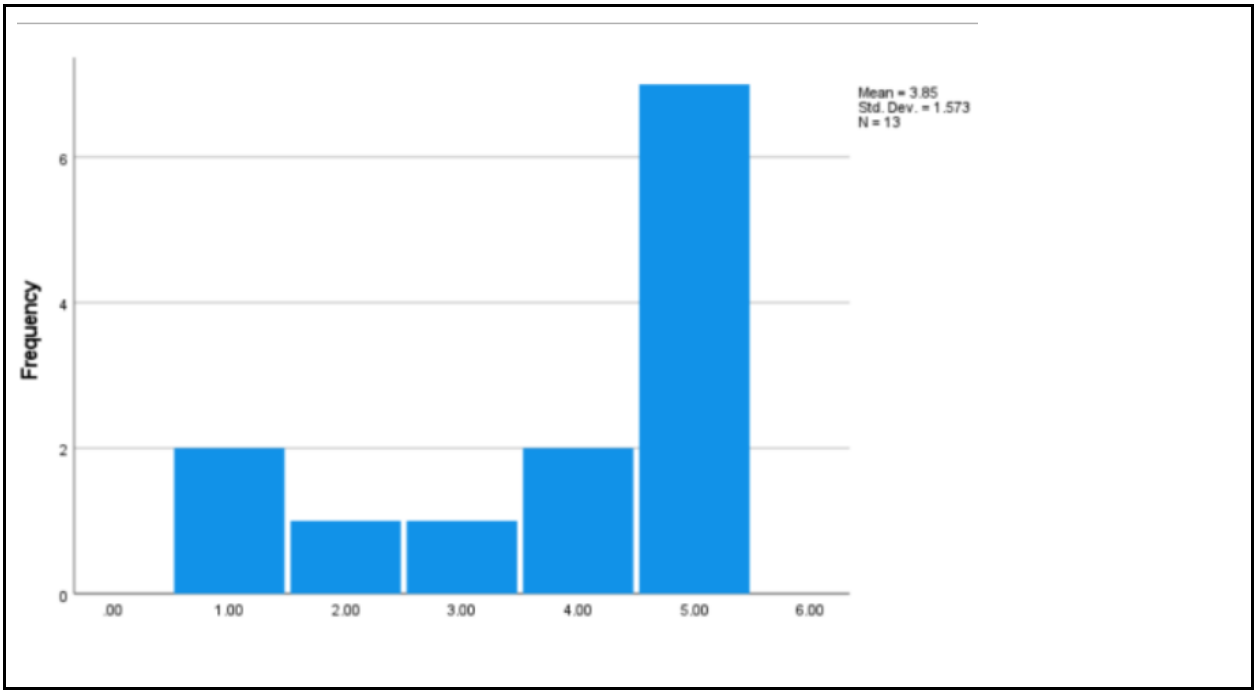
Assignment value

11.



Appendix D: *Post-Survey of 2000-Level Course delivered to students.*

Results from 2000-Level Course Post-Survey
1. *Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?*



Appendix E: *Results from 2000-Level Course Post-Survey that was delivered to BME students.*

Student Survey
3000-Level Course Post-Survey
HCD Overview
1.

Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?

Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
1	2	3 3	4	5

Scale of utility

2.

How important do you think it is to address healthcare disparities in your intended future career?

Not important	Somewhat unimportant	Neutral	Somewhat important	Very important
0	1	2 3	4	5

Importance of HCD in your future career

3.

If WPI were to award a Certificate of Healthcare Disparity Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your resume in the future when applying for jobs, research positions, or further degrees?

- ○ Yes
- ○ No

4.

Do you think the Healthcare Disparity module helped you to understand that certain populations are often left out of design considerations?

0 1 2 3 4 5

Helpfulness of the modules in terms of the design considerations

5.

Do you think the Healthcare Disparity module convinced you that the field of Biomedical Engineering (BME) and the field of healthcare depend on and affect each other?

- ○ Yes
- ○ No

6.

Do you think the Healthcare Disparity module convinced you that it is important for Biomedical Engineers to understand and learn about healthcare disparities?

Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
0	1	2	3	4	5

Persuasiveness of the module

7.

Do you feel more confident in recognizing potential healthcare disparities in your future career or research?

- ◯ Yes
- ◯ No

Module Overview

8.

How engaging were the Course Level Overview slides?

0 1 2 3 4 5

Level of engagement

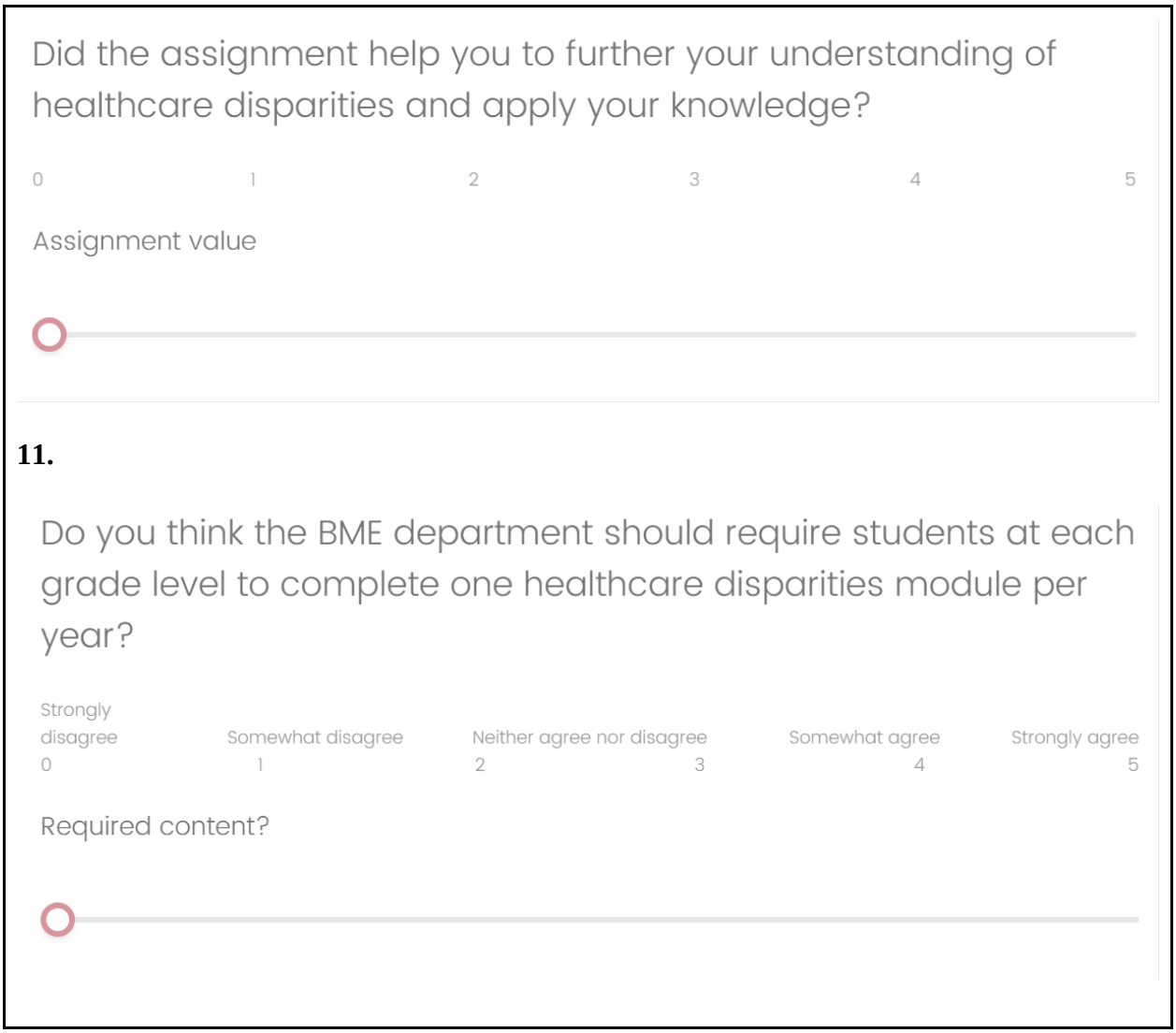
9.

How did you find the organization of the Canvas page?

0 1 2 3 4 5

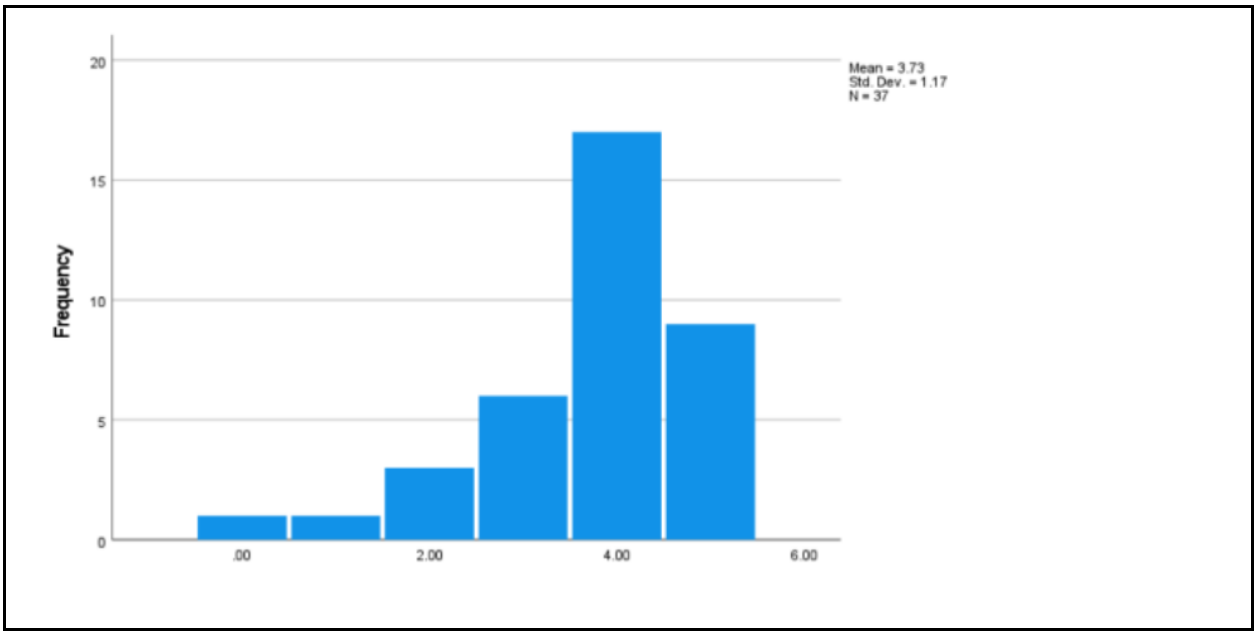
Level of organization

10.



Appendix F: *3000-Level Course Post-Survey delivered to BME students.*

3000-Level Course Post-Survey Results
1. *Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?*



Appendix G: *3000-Level Course Post-Survey results.*

Student Survey
4000-Level Course Post-Survey
HCD Overview
1.

Did the Healthcare Disparities Modules help you to improve your knowledge of healthcare disparities?

Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
1	2	3 3	4	5

Scale of utility

2.

How important do you think it is to address healthcare disparities in your intended future career?

Not important	Somewhat unimportant	Neutral	Somewhat important	Very important
0	1	2 3	4	5

Importance of HCD in your future career

3.

If WPI were to award a Certificate of Healthcare Disparity Awareness and Prevention to students who complete a healthcare disparity module during each course-level while at WPI, do you think it would benefit your resume in the future when applying for jobs, research positions, or further degrees?

- ◯ Yes
- ◯ No

4.

The modules helped me to understand the importance of Cultural Competency for a biomedical engineer.

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
0	1	2	3	4	5

Agreement

5.

Please rate your agreement with this statement:

The modules helped me to understand the importance of Human-Centered Design in BME.

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
0	1	2	3	4	5

Agreement

6.

Do you think you can explain the concept of Cultural Competency?

- ○ Yes
- ○ No

7.

Do you think you can explain the concept of Human-Centered Design?

- ○ Yes
- ○ No

8.

Did the assignment help you to further your understanding of healthcare disparities and apply your knowledge?

0 1 2 3 4 5

Assignment value

Module Overview

9.

How engaging were the Course Level Overview slides?

0 1 2 3 4 5

Level of engagement

10.

How did you find the organization of the Canvas page?

0 1 2 3 4 5

Level of organization

11.

Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?

Strongly disagree 0 | Somewhat disagree 1 | Neither agree nor disagree 2 | Somewhat agree 3 | Strongly agree 4 5

Required content?

4000-Level Course Post-Survey Results

1.

Do you think the BME department should require students at each grade level to complete one healthcare disparities module per year?