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Toward a Health Equity Spine Across Biomedical Engineering Curriculum: A Faculty-Led Collaborative Autoethnography Exploring Lessons Learned

Dr. Ashley R Taylor, Virginia Polytechnic Institute and State University

Dr. Ashley Taylor (she/her) is a Collegiate Assistant Professor in the Department of Biomedical Engineering and Mechanics at Virginia Tech. Her teaching and research focus on mobilizing engineering students to solve pressing real-world challenges through community-based participatory approaches. Taylor has partnered alongside communities in rural Appalachia, Nigeria, Malawi, Tanzania, Kenya, and Ethiopia to cultivate innovation ecosystems and provide hands-on experiential learning education opportunities at nine universities across sub-Saharan Africa and the United States. Together, collaborators from across these universities developed the Invention Education Toolkit (ive-toolkit.org), an open-access resource to support the transformation of engineering education in African universities to solve local and global challenges. Taylor received her Ph.D. in Engineering Education, MPH in Public Health Education, and MS and BS in Mechanical Engineering from Virginia Tech.

Dr. Kinsley Tate, Virginia Polytechnic Institute and State University

Kinsley Tate is an Instructor in the Biomedical Engineering and Mechanics department at Virginia Tech where she teaches courses related to cellular and tissue engineering. She received her BS in Engineering and MS in Biomedical Engineering at East Carolina University. She completed her PhD in Biomedical Engineering at Virginia Tech.

Dr. Andre Albert Muelenaer Jr, Department of Biomedical Engineering and Mechanics, Virginia Tech

Professor of Practice-Biomedical Engineering and Mechanics & Professor of Pediatrics-Virginia Tech Carilion School of Medicine, Virginia Tech. MS-Zoology, Virginia Tech; MD, Eastern Virginia Medical School; Pediatric Residency, William Beaumont Army Medical Center; Pediatric Pulmonology Fellowship, University of North Carolina-Chapel Hill. Fellow, American Academy of Pediatrics and American Chest Society.

LaDeidra Monet Roberts, Virginia Polytechnic Institute and State University
Dr. Christopher Arena, Virginia Polytechnic Institute and State University

Chris is a Collegiate Associate Professor at Virginia Tech in the Biomedical Engineering and Mechanics (BEAM) Department. He received his B.S. degree from the University of Virginia and Ph.D. degree from Virginia Tech, both in Biomedical Engineering. He teaches senior design, clinical needs assessment, and biodesign fundamentals. Chris is passionate about collaborations that facilitate student experiential learning opportunities and his research is focused on medical devices, with ongoing projects in the areas of lymphedema treatment, wound healing, and sensory neuroprosthetics.

Dr. Sara L Arena, Virginia Polytechnic Institute and State University

Sara L. Arena received a B.S. in Engineering Science and Mechanics (2007), M.S. in Biomedical Engineering (2008), and Ph.D. in Biomedical Engineering (2011) from Virginia Polytechnic Institute and State University (Virginia Tech). She currently serves as the Biomedical Engineering Undergraduate Program Chair and Collegiate Associate Professor in the Department of Biomedical Engineering and Mechanics at Virginia Tech. Sara's research within engineering education has focused on active learning strategies within foundational undergraduate courses, including cooperative, collaborative learning, and problem-based learning. Sara additionally focuses on assessment methods related to accreditation. Outside of pedagogical research, Sara is also active in research related to the biomechanics of human movement, serving as the Assistant Director of the Kevin P. Granata Biomechanics Lab at Virginia Tech. Specifically, her recent research interests have focused on postpartum movement mechanics.

Toward a Health Equity Spine Across Biomedical Engineering Curriculum: A Faculty-Led Collaborative Autoethnography Exploring Lessons Learned

Introduction

Increasing health disparities are an urgent concern, with some counties in the United States even facing lower life expectancies in 2014 than in 1980 [1], [2], [3]. The Centers for Disease Control defines health disparities as "preventable differences in the burden of disease, injury, violence, or opportunities to achieve optimal health that are experienced by socially disadvantaged populations" [4]. Factors including race, ethnic background, class, gender, and place are well established as contributing to differences in health outcomes in the United States [5]. Social determinants of health and implicit bias have also been a documented component of the complex drivers of health inequity. However, only more recently, health technologies have come under scrutiny for their role in perpetuating health inequities [6]. Amidst this landscape, biomedical engineering (BME) education is amplifying its calls to action, with a clear goal to improve students' preparedness for addressing health inequities [6], [7]. In the compelling words of Lanier et. al [6]: "As biomedical engineers developing the next generation of healthcare technologies, we are poised to either improve the health disparity landscape or further widen the gap."

Despite a shared recognition of the importance of integrating health equity principles into BME curriculum, STEM curriculum has traditionally lacked engagement with health equity concepts [8], [9], such as health disparities [7]. Additionally, few best practices are documented in the literature to support engineering faculty in integrating health equity concepts into their courses. Adding to these challenges is the risk of "fragmentation of the curriculum" through content that is disjointed across curricular levels [10], [11]. The Association of American College and Universities, in their Greater Expectations Report, flag fragmented curriculum as a major barrier to excellence in university education [12]. Notably, university curricular pathways more broadly have been historically criticized [13] for having "disparate and unconnected courses, instead of an integrated experience" [10]. Curricular pathways that fail to bridge and connect student learning outcomes across curricular levels (e.g., sophomore, junior, and senior courses) miss profound opportunities to prepare future engineers for the interconnected knowledge they will need in their future work [14].

For these and other reasons, there is a trend in engineering education toward integrating a "spine" of content that develops core competencies across multiple courses—at all curricular levels—as a best practice. For example, embedding a "spine" of context-specific communication skills across core engineering courses is widely viewed as a best practice in engineering education [15]. Similarly, numerous examples exist of curricular innovation to develop a design "spine," also referred to as a design backbone, across engineering curriculum with a growing number of examples in biomedical engineering education specifically (e.g., [16], [17], [18], [19], [20]) to support students' deep mastery of design learning outcomes. In addition to the design spines of many BME programs, recent work in BME education has highlighted examples of the integration of ethics as a spine for BME curriculum [21]. Despite the progress for design and ethics as curricular "spines" in BME, only a few works in progress exist (e.g., [22]) to consider how to incorporate health equity across multiple levels of courses within BME curriculum. Combined, the lack of existing models for incorporating health equity into BME curriculum alongside the timely call to action for BME to advance health equity [6] presents an urgent

opportunity to expand our understanding of effective practices for integrating health equity into BME curriculum.

We aim to contribute to this gap in literature through sharing insights from a collaborative autoethnography of six biomedical engineering faculty members exploring lessons learned while integrating health equity concepts into core undergraduate BME courses. Located at an R1 institution in the southeastern United States, faculty participants hold experiences reforming curriculum to include health equity context across six core courses and one advanced undergraduate technical elective. Combined, these efforts span the sophomore, junior, and senior years of study at the institution, creating an emergent "spine" of health equity across the BME curriculum.

Purpose and Research Questions

The purpose of this research paper is to describe findings from a faculty-led collaborative autoethnography exploring insights from the integration of health equity concepts across six core courses and one advanced technical elective in an undergraduate biomedical engineering (BME) program curriculum. Our collaborative autoethnography examines the following research questions (RQ):

RQ1: Why do faculty revise their BME courses to incorporate health equity concepts?

RQ2: How do BME faculty integrate health equity concepts into undergraduate BME courses?

RQ3: What best practices can be illuminated to support further health equity-focused curricular reform?

Conceptual Framework: The Academic Plan

To establish a shared vocabulary for exploration of our research questions, we leverage Lattuca and Stark's [23] Academic Plan Model to underpin our collaborative reflections. The Academic Plan Model is a framework for understanding decisions that drive changes to curriculum, including planning and implementation. We specifically leverage eight elements of the framework as a set of sensitizing concepts [24] to support shared understanding and meaning making in our reflection processes; these included *purpose, content, learners, instructional resources, instructional processes, assessment and evaluation, sequence*, and *educational environment*. Additionally, the layers of contextual influences defined in the Academic Plan Model—including external, institutional, and internal influences—also provide a useful set of thinking tools for our data collection and analysis. Due to our focus on understanding multi-level, health equity-focused curricular change, Lattuca and Stark's [23] framework is a practical underpinning for considering curricular revisions across curricular levels (e.g., course, multiple courses, or project).

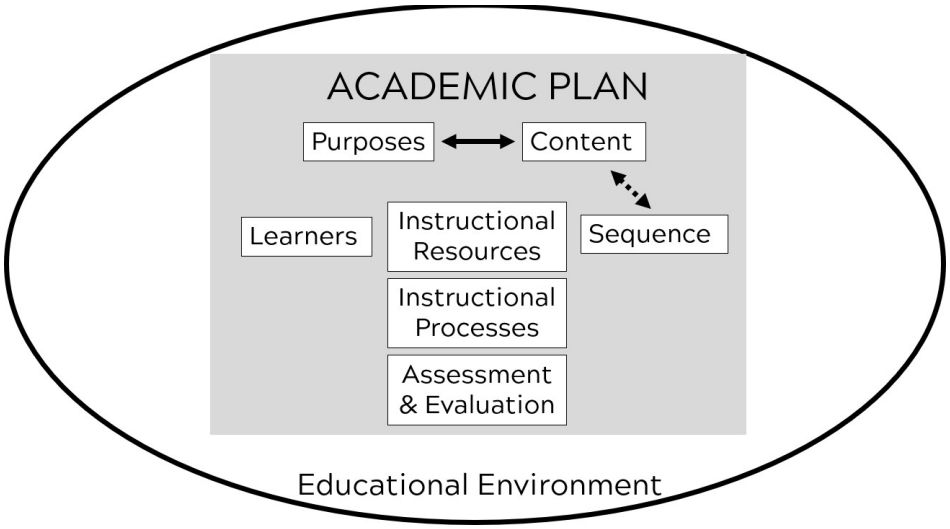

Figure 1. Elements from Lattuca and Stark's [23] Academic Plan Model were used as a theoretical underpinning for our study.

Biomedical Engineering Program Context

Our program context is the undergraduate BME program at an R1 institution in the southeastern United States. Our ABET-accredited BME program was newly established in 2018, with the first cohort of undergraduates graduating in May 2022. At the time of writing, our BME program currently enrolls ~250 undergraduate students seeking a B.S. in BME, with an additional ~80 students pursuing a minor in BME. For over two years, faculty across the tenure and teaching tracks have worked to integrate health equity concepts into core engineering curriculum. With these combined efforts, health equity content—typically through integration of problem-based learning modules—has been integrated into six core BME courses and one advanced BME technical elective as shown in Figure 2.

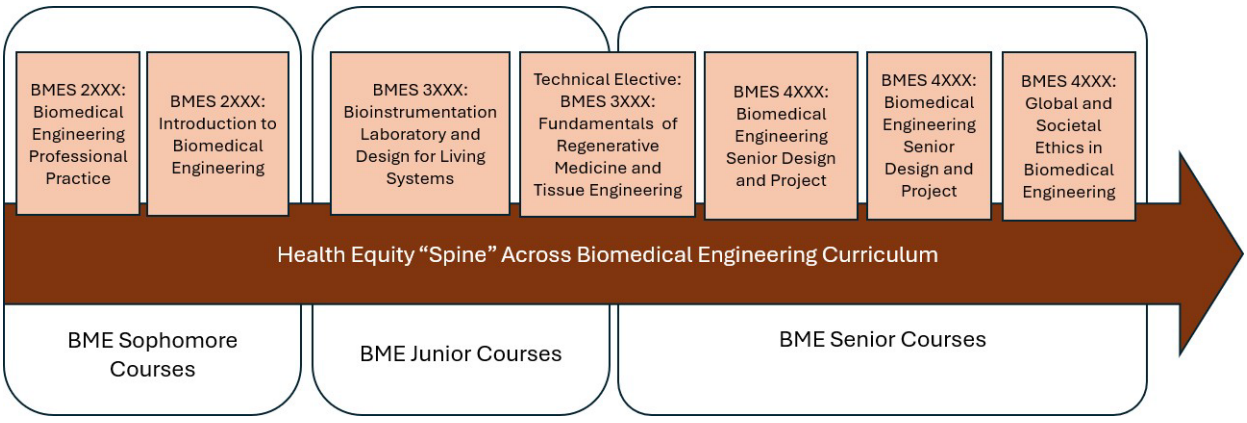

Figure 2. Illustration of biomedical engineering courses across our undergraduate BME program that have incorporated health equity.

Research Methods

Research Design and Data Collection. To explore our research questions, we used a collaborative

autoethnography (CAE) process. Emerging from ethnographic methods, which are growing in popularity among engineering education researchers [25], CAE is a systematic, qualitative inquiry method that emphasizes deep reflection in order extract higher level insights [26]. As a research method, CAE is a pragmatic tool that scaffolds researchers' reflections on their shared experiences surrounding a given topic to inform research insights [26], [27]. The highly collaborative nature of CAE drove our decision to leverage this method, providing a structured mechanism for us to share and co-learn from each other [28] and strengthening the potential impact by embracing diverse perspectives [29]. Practically, the CAE process enabled our team of BME faculty to participate in iterative cycles of reflection, both as individuals and as a group, toward collective sense-making of themes across our experiences [24], [30] integrating health equity into BME curriculum. This work does not use data from humans outside of personal reflections the study's authors and therefore does not meet the definition of human subjects research; IRB review is not required.

As shown in Figure 3, our data collection processes occurred in three stages, coordinated by the lead author who is an engineering education researcher. During Phase 1, reflective prompts were developed using Lattuca and Stark's Academic Plan Model [23] as a guiding framework. For example, faculty were asked to reflect on specific elements from the Academic Plan Model through reflection prompts, such as "*describe your **learners** in the course" and "describe your **purpose** for incorporating health equity concepts in your course curriculum."* Additionally, faculty were asked to share specific descriptive examples of how they incorporated health equity concepts and reflect on successes and challenges. During Phase 2, BME faculty completed individual written reflections in response to the reflective prompts. Reflections were completed asynchronously. Finally, during Phase 3 of data collection, we met as a group to share reflections and identify cross-cutting themes in our experiences. We recorded and transcribed this meeting to support data analysis.

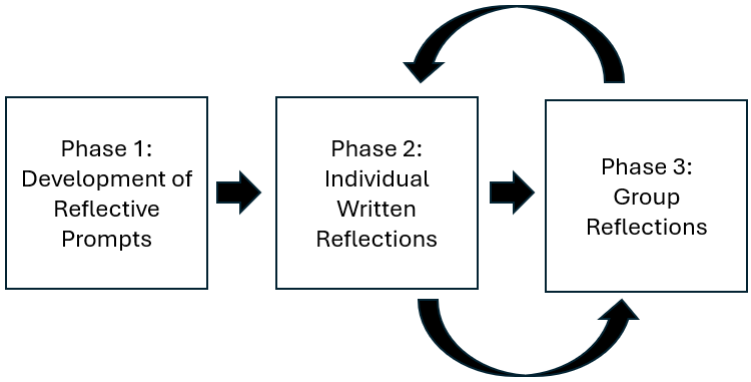

Figure 3. Our data collection methods used a combination of individual and group reflections to enable sharing of knowledge and co-learning.

Authors' Positionality and Context. Given the reflective nature of CAE processes, it is imperative to provide a brief overview of the positionality—or background—of the authors. All authors are faculty members in a biomedical engineering program at an R1 institution in the southeastern United States. Faculty authors represent a variety of lived experiences and technical areas of research focus, ranging from tissue engineering to biomechanics to pediatric pulmonology. Faculty also represent teaching track and tenure-track research positions, providing unique

insights about curricular transformation initiatives across varied faculty roles.

Data Analysis. Qualitative coding methods were used to construct thematic narratives across individual and group reflections. We specifically used inductive coding and the constant comparative method [31] to identify themes in the data. While CAE reflections can be presented in diverse ways (e.g., "script" structure in seminal engineering education research example [32]), we ultimately chose to structure our results into thematic narratives, similar to Holly & Lee's recent CAE in engineering education research [28].

Research Measures of Quality. To support our research quality, our process was facilitated by an engineering education researcher who also has experience integrating health equity across BME courses, with quality measures underpinned by Le Roux's [33] five evaluation criteria for autoethnographic research: contribution, credibility, resonance, self-reflexivity, and subjectivity. We summarize the application of these quality measures in Table 1.

Table 1. Measures of Quality for Collaborative Autoethnographic Research

Measure of Quality	**Le Roux's Definition**	**Applied to our study**
Contribution	Study should extend knowledge, improve practice, or contribute to social change [33]	We leverage CAE in an effort to expand understanding on effective integration of health equity curriculum for the broader field of biomedical engineering education.
Credibility	Honesty is central to the research process [33]	Faculty shared experiences openly in a group setting after individual reflections, with iterative opportunities to expand on and/or clarify their reflections
Resonance	Narratives are written with a goal of enabling the broader audience to engage with and connect to the experiences. [33]	We constructed our thematic narratives with the primary audience of biomedical engineering educators, with the goal of enabling educators to draw connections to their own educational contexts
Subjectivity	Self and self-understanding are underpinning the research method, with researchers actively involved in sharing their own narratives [33]	Individual reflections were utilized before group reflections, with the unit of analysis centered on faculty member's personal experiences.
Self-Reflexivity	The researchers demonstrate intense awareness of their roles in and relationship to the research which is situated within a historical and cultural context [33]	Numerous examples of faculty situating their narrative and personal experiences in a broader historical and cultural context are present in the data, as discussed in the results section

Limitations. Our primary limitations in this research study are twofold. First, collaborative autoethnographies are limited in their dependency on individual's memory to create reflections about their experiences, such as discussed in [34]. Though including a small number of participants istypical

for CAE processes, we acknowledge that our study may be limited by the number of faculty engaged in the CAE process (n=6), with opportunities to expand the number of faculty participants in future work.

Results

Below, we share results from our collaborative autoethnography. First, we share themes from the data illuminating insights about faculty's motivation for incorporating health equity into their courses (RQ1). Next, we highlight descriptive examples of how faculty integrate health equity into biomedical engineering courses across a variety of curricular levels—lectures, projects, and full courses (RQ2). We conclude our results section by discussing best practices for incorporating health equity into existing BME curriculum that can be extracted from our data (RQ3). Through the sharing of these reflections, our goal is to enable faculty to adapt and translate best practices for integrating health equity into their own biomedical engineering education contexts.

Why Faculty Revise BME Curriculum to Include Health Equity (RQ1)

One key question we explored was *why* BME faculty change their curriculum to include health equity; in other words, amidst many competing priorities for their time, what underpins faculty motivation for revising their curriculum to include health equity concepts? Our data clearly highlights four themes in motivation for curricular transformation as described by faculty including 1) Fundamental and Inseparable: Health Equity in BME Mission and Duty, 2) Forward From Failure—Changing the Health Technology Landscape, 3) Responsive to BME Students' Experiences and Interests, and 4) Preparing Biomedical Engineering Graduates to Solve Complex Challenges. Below, we elaborate on each of these themes.

Theme 1: Fundamental and Inseparable: Health Equity in BME Mission and Duty

One of the most salient themes that emerged across data sources was faculty's view of health equity as central to, rather than supplemental to, the field of biomedical engineering. Faculty discussed health equity as connected to the "mission" of their department, institutions, and even their personal mission. At the highest level, faculty made distinct connections between health equity and the "mission" of the biomedical engineering profession. For example, Monet noted in her individual reflection that "*incorporating health equity into the course curriculum directly aligns with the mission of a biomedical engineer*" and later elaborated in the group reflection, "*[it] is framed within the fabric of who you are as a biomedical engineer.*" At a more localized level, faculty made connections to the mission of their home academic department, noting that improving the human condition—which they connected to advancing health equity— is "*literally on the [department] website.*" Sara pointed to her views on the alignment between health equity and the mission of the university, sharing:

"Ut Prosim – that I may serve – is a core mission for the university and the department – to improve the human condition. The curriculum / assignments stay the same, but we use existing real-world problems as a lens for application – adding in health equity related problems engages the students in a different way as it also challenges them to think outside of their own experience."

Two faculty members also connected personal experiences to their motivation for integrating health equity into BME curriculum. For example, Monet shared:

I would say from a more personal perspective as well, and I'm sure other people can also empathize, I would say for me, being an African American woman, there are things that we know from different case studies over the years that have historically impacted those who share my same ancestral background, as well as others. …So for me, I have a vested interest in terms of [making] sure that students are aware of those things that have happened and how other communities are being impacted even in the present. I mean, you have a lot of diseases-- such as sickle cell disease, some forms of breast cancer, etc., cardiovascular disease—that disproportionately affect those within my community for various reasons. And so for that—really teaching students from that perspective – [I have] a vested interest in these topics for health advances from the present to beyond. These are things that I-- you know, about triple negative breast cancer, quadruple negative breast cancer, which I just found out about a year ago in terms of disproportionately impacting African American women [and] sharing this [with students]… who are thinking about… these different health equity issues. There are things that are constantly evolving in terms of disease and pathology.

Andy, in his written reflection, similarly shared his personal mission to advance health equity informed by his lived experience as a physician:

"My answer to the Why? 40 years of medical practice, observing the inequity associated with social determinants of health here in the USA, and seeing these inequities magnified as I traveled the world."

Beyond direct connections to personal, departmental, institutional, and professional missions, faculty also reflected seriously on concepts of their "duty" to incorporate health equity into biomedical engineering. Monet reflected on the duty of biomedical engineers to consider health equity and her discussion on these topics with her students:

"One of the things I instilled in them at the end of the class… you get to be the voice of the voiceless. You get to have a seat at the table where a lot of other people don't have that seat, and you get to think about these different aspects that maybe not a lot of other people get to think about because of your perspective as a biomedical engineer. You know you have engineering principles, but you're applying it to increase the quality of life for others. That's the duty that we have…That's what we all do and so you have a duty to uphold that."

Connecting with notions of duty, several faculty drew parallels between health equity and codes of ethics for biomedical engineers. For example, Andy reflected on his motivation for developing an ethics-focused course for biomedical engineers and integrating health equity concepts:

"Some [BME] students will be going into industry, but never interface with clinical medicine. Others will practice hand-in-hand with healthcare providers. Others will follow academic careers, while some will go on to professional careers. Most will have some relationship that affects the health and well-being of patients. With the explosion of information and communications technologies, the world is smaller. We impact the lives of many different cultures, economies, political systems, etc."

He elaborated to describe his course's curricular focus on biomedical engineering in the context of sub-Saharan Africa and shared his communication to students at the start of his course:

"While most of you will never travel to a low- or middle-income country, you will impact vulnerable populations here in the U.S. and abroad… The overall goal of [this course] is then to

instill the students with the confidence to engage with others to identify and create solutions to health-related problems on a global basis, while addressing ethical considerations of engineering as noted in the National Society for Professional Engineers."

Combined, faculty's reflections across this theme highlight deeply held beliefs about health equity as a core component of "duty" and "mission" for biomedical engineering.

Theme 2: Forward From Failure—Changing the Health Technology Landscape

A second resounding theme that emerged in the data as a motivator for faculty changing their curriculum to include health equity was a sense of urgency around turning the tide on current bias in existing health technologies. Notably, faculty narratives highlighted many examples of existing health technologies that are not designed to work effectively for all populations, with disproportionate impacts often noted for marginalized populations. For example, Kinsley discussed the example of gender gaps in the design of automobile safety mechanisms, such as seat belts:

"An example that we talked about in intro to BME when I taught this course in the Spring 2023 semester is the idea of looking at car crash studies, and how seatbelts are really designed for the average size male. Female size was not originally considered in seatbelt design. So, if you're born female, you are more likely to get seriously injured in a car accident. This shows how important it is to consider different backgrounds of end users, regardless of whether you are designing a seat belt or medical device."

Similarly, Monet shared an example she discusses with her students about the ongoing challenges with systemic racism in electroencephalography (EEG) research, as recently discussed in the literature (e.g., [35]). She shared:

"when you think about medical device design for instance, we had the assignment [for the students] on learning how to read a journal article… I picked a paper specifically that talked about electrodes for African American or melanated skin in terms of the accuracy not being the best… in terms of actually getting accurate readings for EEGs. And so for that-- I thought that was really important in terms of a lived experience. Picking papers from people in my community who have written those papers and done that work was really actually special to me—to actually show and talk to the students directly about knowing the people who are working on these technologies directly and how it is a really important thing to think about how you need to be looking at things such as skin color or… ethnic ancestry background [in] medical device design."

Expanding on the current limitations of medical device design processes, faculty discussed motivations for improving global access to health technologies. Notably, faculty often painfully shared examples from their personal research spaces of cutting-edge inventions in BME that remain unavailable to large portions of the global population, ultimately limiting their intended positive impact on health outcomes. For example, Kinsley shared an example from her research expertise in regenerative medicine:

"Biomedical engineers are exposed to the newest treatments and cutting-edge science within the regenerative medicine field. Unfortunately, there are many people here in the United States and globally that are unable to access these life-saving treatments. For example, gene therapies have recently been created for the treatment of sickle cell anemia which affects millions of

individuals across the world. A majority of the people affected by this disease live in parts of the world that do not have access to the technologies that can grow and administer cell-based therapies to patients. As a class, we discuss topics like these to understand how we can meet global health needs in the regenerative medicine field and while simultaneously increasing health equity. While the regenerative medicine field holds promise for the development of novel treatments, there is a great need to discuss how to get these treatments to individuals who need them. I decided to include health equity topics in my course to make sure my students are aware of global needs that can be solved using biomedical engineering techniques and to encourage them to find ways to solve these problems. Many of my students are pursuing a degree in biomedical engineering because they wish to make a positive impact on healthcare. By discussing health equity in BME classes, we empower students to use skills gained from their degree to increase health equity for people across the world.

Kinsley later expanded on her written thoughts during the group reflection, highlighting the lack of global access to cell therapies—particularly in low resource settings—as a driving motivation for incorporating health equity into her advanced technical elective course:

"Fundamentals of Regenerative Medicine is a technical elective, that's typically taken by BME undergraduates who are juniors or seniors. This class covers everything from tissue engineered implants to cell-based therapies. What I love about this class is that it covers cutting-edge research that holds promise for the future of medicine. I guess I'm a little bit biased, but I believe that we have a lot of really groundbreaking gene therapies now and regenerative medicine treatments that didn't exist in the past 10 years. Unfortunately, what happens is we have these amazing "solutions" to certain diseases… For example, there is now a gene therapy that can treat sickle cell disease, which affects people across the world. Millions of people. Unfortunately, a lot of people in Africa and other areas around the world cannot access these cell-based therapies due to lack of resources to actually grow cells in a sterile manner within the local environment."

Combined, these excerpts from faculty narratives illuminate an urgency felt by faculty to integrate health equity curriculum to help students grasp the impact of their biomedical engineering work on improving on the human condition—particularly for populations presently and historically marginalized.

Theme 3: Responsive to BME Students' Experiences and Interests

A third theme that emerged in faculty's reflections on their purposes for incorporating health equity was a desire to be responsive to students' lived experiences and interests. Several faculty shared that a driving reason for incorporating health equity into their curriculum was to harness the motivation of students and support them in pursuing meaningful areas of biomedical engineering work. For example, Kinsley shared about her desire to acknowledge the lived experiences of students that may intersect with health (in)equity:

"I think something about health equity that's so important is when a student comes into your class—you don't know what they've been exposed to at that point. So some students may have never thought about health equity. But some have had personal experiences with it. So I think we are obligated in the sense that we are already teaching students really important biomedical engineering information that we should be also be including healthy equity topics in our coursework that are equally important."

She later elaborated about students' motivation for health equity in biomedical engineering, sharing:

"What I love [about our BME students] is so many of them are really excited about making a positive difference in healthcare. Many of them know they want to make a difference but they are not sure how. So when they go through classes and hear these different examples [of health equity intersections with BME]—they find what they're passionate about. I think it's exciting that so many of them are looking for a way to impact the world in a positive manner."

Faculty reflections surrounding student interest in health equity content indicate a desire to be responsive to students' lived experiences and passions as a driving force for integrating health equity into their curriculum, ultimately increasing student motivation for learning.

Theme 4: Preparing Biomedical Engineering Graduates to Solve Complex Challenges

A final theme that emerged in faculty narratives about motivation for incorporating health equity into curriculum was a pragmatic focus on preparing engineers to solve the complex challenges of our time. Faculty highlighted the practical necessity of BME student preparedness to engage with diverse stakeholders, and the need to be holistically prepared to consider multifaceted external constraints when designing BME solutions. Chris described his motivation for giving his BME students a "differentiator" in career preparedness compared to other engineering disciplines, sharing:

"I think [integrating health equity] is also a unique opportunity for our students to differentiate themselves from the other facets of engineering—if we're able to create this time in the curriculum where they can consider these factors at a deeper level. And then you see that ultimate goal of, you write it down on paper in a problem statement and engineering requirements, but, it manifests in this better product or service that's meeting needs in a better way. Then I think [BME students] can really stand above some of their other counterparts that may not have that opportunity to consider those factors that deeply in their design."

Andy also highlighted the importance of health equity in BME career preparedness, pointing to the importance of considering the diverse range of healthcare contexts BME students will someday work in. From his perspective as a clinician and faculty member, he shared:

"From a physician, you know, health care practitioner perspective, we don't all just operate in in the ivory towers of academic medicine. Even here in the United States, the spectrum of care goes from large medical centers associated with universities all the way out to very remote clinics in the Navajo Nation, in Alaska, and other places. And so, [a medical device] that works for the end user at a large medical center may not be appropriate for use by someone who's in a remote area… [there is a variety of] need in a variety of settings."

Ultimately, faculty reflections in this theme highlighted the importance of adequately preparing BME students to effectively work across a variety of complex challenges; they viewed the integration of health equity concepts as a strategy for increasing career readiness.

How Faculty Integrate Health Equity into BME Courses (RQ2)

Our second guiding question centered on understanding *how* faculty work to integrate health equity into their BME courses. Put another way, we worked to examine the strategies that faculty leverage to revise curricular content focused on health equity. Three key themes emerged from

faculty reflections highlighting distinct strategies for incorporating health equity into existing BME courses. First, faculty highlighted opportunities for curricular change at multiple curricular levels—for example, changing a single active learning class activity, changing an entire course project focus, or changing an entire course. While it can be overwhelming to revise an entire course, it was striking that faculty primarily highlighted their experiences working to integrate curricular change in scoped and strategic ways within *existing* curriculum. For example, Kinsley shared her strategies to embed health equity in her regenerative medicine course:

"Health equity is so important that we should be including it in our coursework, even if it's just one health equity devoted lecture or incorporating it in class examples throughout the semester. Including some health equity content is better than nothing, right?... One day of the entire semester is devoted to discussing how to meet global health needs with regenerative medicine. We start this lecture with defining what global health is. From there, we talk about the COVID-19 pandemic and how during that time we had vaccines, but some brands had to be in cold storage initially. So countries had to have access to - 80° freezers nearby. A lot of places in sub-Saharan Africa, didn't have access to that kind of cold storage and so they were not able to acquire vaccines as quickly as other places around the world. Another company developed a vaccine that was shelf stable and could be transported and used in sub-Saharan Africa. One lesson from this example is you have to think about the different end users of your product and how they may have different environmental conditions. I encourage my students to think about that [in our work] and to make [their designs] accessible for everyone."

With a similar focus on actionable curricular reform, Monet shared a strategy she used to modify her existing curriculum by adding considerations for vulnerable populations to a problem-based learning module. She described a long-standing project in the program's BME curriculum where students develop an agent-based model to simulate disease transmission using MATLAB. Historically, student projects have examined transmission of COVID-19, Tuberculosis, and Respiratory Syncytial Virus. Monet described modifying a specific active learning activity to teach agent-based modeling to students to incorporate a health equity lens more explicitly. She incorporated specific rules in the agent-based modeling simulation activity asked students to consider immunocompromised populations for students to reflect on the broader implications of health equity in infectious disease transmission. She describes introducing the concept of immunocompromised for their modeling project with an active learning exercise:

"In terms of the agent-based modeling activity that I did… I [assigned students] with a sticky note in terms of being remote workers, essential workers, and healthcare workers. But then I also added an extra element to it where, if they were immunocompromised, they would have a sticker on that sticky note. …I had the students play rock, paper, scissors with a specific number of different people based on the rules [in the context of] with agent-based modeling. You have to play with this many people if you're immunocompromised and [if] you lose rock, paper, scissors, then instead of you getting just one X [for the loss on your sticky note], if you're immunocompromised, you actually have to put 3X's per each loss. To show that you are significantly impacted by… the transmission of the disease. …That was really nice to actually bring more active learning instead of it just being lecture based."

Chris also highlighted actionable pathways to integrate heath equity into capstone design curriculum. He described his curricular innovation work to incorporate health equity into curricular focused on identifying design project needs and constraints:

"One of our main learning objectives for BME seniors is synthesizing relevant information to identify project needs and design constraints and engineering standards with consideration of public health, safety, welfare, social, global, cultural and economic constraints. Over the past few years, as I've started to learn more about the social determinants of health, which are education access and quality, healthcare access and quality, economic stability, social and community context, and neighborhood and built environment--you can see just in the overlap of terminology that exists there-- I think that desire to bring in more health equity concepts into Capstone. So it's an ongoing process for us."

Expanding on the actionable strategies for curricular integration, one additional salient thread that emerged across faculty narratives was the opportunity to align health equity curriculum existing Accreditation Board for Engineering and Technology (ABET) student outcomes under Criterion 3 [36]. Specifically, faculty shared examples in their narratives of working to align health equity curriculum with Student Outcomes 2, 3, and 4:

- Student Outcome 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.
- Student Outcome 3: an ability to communicate effectively with a range of audiences.
- Student Outcome 4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

One practical example is seen in Chris's reflection on reforming capstone design curriculum to include health equity concepts toward a more robust student attainment of ABET Student Outcome 2, focused on design. He shared about his ongoing curriculum reform work, highlighting a specific example of helping students make connections between health equity and defining the problem in the engineering design process:

"One of the main assignments that we had relative to the external constraints was a combination of a brief lecture on the ABET design constraints with examples of things that should be considered for different types of design projects, time for individual reflection specific to the students' projects, and synthesis of findings into a team design history file …what we started to do this year that was different… was having one of our graduate student [teaching assistants] come in, who's been studying this topic more in depth. She's been researching really at the problem definition level about how we can do a better job… defining the problem such that we're promoting products that have a better chance of also promoting health equity. She came in and gave a mini lecture on some of her learnings related to eliminating bias in design and engineering from a social point of view…[she] laid out the engineering design timeline for the students, but added in a critical box at the beginning [of the design process] about really spending time defining the problem in a social context."

In addition to integrating health equity with ABET design-focused student outcomes, faculty also highlighted opportunities to integrate health equity into communication-focused curriculum (ABET Student Outcome 3) as well as engineering ethics (Student Outcome 4).

In summary, when collaboratively exploring how faculty integrate equity into their existing BME curriculum, cross-cutting themes across faculty experiences centered on starting by enacting change at an actionable level (e.g., one lecture or one assignment). Faculty also emphasized opportunities to align health equity content with ABET Student Outcomes under Criteria 3.

Best Practices for Future Integration of Health Equity into BME Curriculum (RQ3)

Finally, when prompted to reflect on best practices for integration of health equity into BME curriculum, faculty offered several practical insights, which we summarize below:

1. Amplify the voices of colleagues and stakeholders with relevant expertise and experiences

First, a key recommendation as a "starting point" for integration of health equity was to partner with colleagues with expertise in public health or associated health equity- focused spaces. For example, Sara noted: "*definitely having someone with experience in that area as a good sounding board. Sometimes I feel like it can do just as much damage to represent something incorrectly as well as just avoiding it all together. So I think making sure you have either a good sounding board or good stakeholders involved is a good practice."*

2. Consider adopting place-based challenges that are geographically relevant to your university context. Faculty described abundant opportunity for problem-based learning in BME curriculum by identifying local, community-based challenges. For example, several faculty highlighted their work to incorporate problem-based learning curriculum focused on Neonatal Opioid Withdrawal Syndrome, a condition in which newborns experience symptoms of opioid withdrawal that are difficult to monitor and treat. This pressing challenge is geographically relevant to our university's location in the Appalachian region, which is disproportionately impacted by the opioid epidemic. Kinsley spoke about the value in place-based BME curriculum, noting *something that I love that Ashley did in her classes was she brought in some local health issues related to the opioid epidemic in Appalachia specifically. And I think that it kind of brings it closer to home for a lot of students and if you can try to relate [health equity issues] to students in a way where it feels like it's happening just down the street, that sometimes can be really powerful as well-- if you can identify those kind of problems*."

3. Leverage existing health equity resources. Faculty also noted that a practical entry point to curricular revision efforts is to consider incorporating resources on health equity that are publicly available. For example, Andy mentioned his work to incorporate the research ethics training of the University of Oxford (https://globalhealthtrainingcentre.tghn.org/) Global Health Network into his senior BME ethics course. Utilizing existing resources can diminish barriers for curricular change by reducing time investment from faculty who wish to incorporate health equity into their own work.

Discussion and Conclusion

In conclusion, our collaborative autoethnography illuminated findings from the experiences of six faculty working to integrate health equity curriculum across biomedical engineering courses. First, we explored *why* faculty are motivated to embark on these curricular change initiatives, recognizing multifaceted time constraints. We learned that the faculty involved in this study see

health equity as central to the mission and duty of the BME field, driving their decision to ensure their courses include such content. Notably, five of six authors had no formal training in health equity concepts; instead, a combination of lived experiences with health equity challenges and personal research insights into health equity data gaps catalyzed faculty motivations for incorporating health equity into their BME courses. One of the six faculty authors had formal experience in health equity training through graduate studies in public health, which she pursued based on lived experiences with health disparities and a desire to bridge BME with public health. Broadly, faculty also discussed motivations rooted in moving forward from existing equity "failures" in health technologies, citing needs to increase access to existing technologies and ensure newly developed technologies equitably serve all populations. Faculty also discussed health equity as a potential way to differentiate BME graduates from other engineering disciplines and support career preparedness. By integrating health equity into design curriculum, in particular, faculty discussed giving BME graduates a strategic advantage for their future work by ensuring they are prepared to tackle complex challenges.

When exploring *how* faculty integrate health equity into existing BME courses, a salient theme emphasized across faculty narratives was to start curricular change efforts in actionable ways. For example, faculty discussed modifying their existing course projects to include vulnerable populations, such as incorporating people who are immunocompromised into a disease transmission modeling project. Faculty also discussed devoting one class period to global health applications of tissue engineering, for example, imploring students to consider how to make their designs accessible at the very early stages of the design process. Finally, faculty highlighted strategies to align health equity curriculum with ABET accreditation criteria. Specifically, ABET Criteria focused on communication, design, and ethics were highlighted as well-positioned for incorporation of health equity concepts. Combined, faculty narratives demonstrate actionable strategies for best practices toward incorporating health equity into BME curriculum, including partnering with relevant stakeholders, leveraging existing curricular resources, and identifying place-based challenges for problem-based learning criteria.

We undertook this research exploration to collaboratively explore the emergent spine of health equity concepts integrated across seven of our courses in BME. We imagine that "spines" of content in BME curriculum are likely most often designed and then implemented as a best pedagogical practice; yet, the health equity "spine" across our BME curriculum emerged somewhat organically, with curricular change led initially led at the course-level by individually faculty. Upon recognizing the convergence of the significant health equity-focused curricular reform across our core courses, we came together to understand why and how this change process was happening. As a research method, the collaborative autoethnography tools provided a powerful mechanism for understanding the faculty-led curricular changes in our program.

Building on the insights from exploring *how* and *why* health equity is being integrated across BME courses, our most important next step is to thoughtfully 1) identify threshold health equity concepts for BME students across curricular levels, 2) collaboratively consider how to connect and expand these concepts to strengthen the health equity spine across our courses, and 3) systematically assess the impact of these curricular change efforts on students' achievement of

learning outcomes. We see a timely and urgent opportunity to ensure BME curriculum is responsive to the most complex challenges of our time, which—as faculty discussed in their narratives—often intersect with health (in)equity. Ultimately, the aim of this research is to support BME educators who seek to integrate health equity concepts into their curriculum, as we collectively seek to strengthen the preparedness of BME graduates to address health disparities through their work.

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