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Teaching Freshmen Empathy through a Health Inequity Design Challenge

Dr. Eileen Haase PhD, The Johns Hopkins University

BS ESM Virginia Polytechnic Institute & State University MS EE Johns Hopkins University PhD Biomedical Engineering, Johns Hopkins University

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Abstract

Freshmen in a two-credit biomedical engineering course were given the World Health Organization (WHO) definition of health inequity on their first day of class. Guided by an upper classmen lab manager, students worked together in teams of five on a semester-long Health Inequity Design Challenge. Freshmen had a combination of individual and team assignments to gain knowledge in both health inequity and the design process. Throughout the semester, students heard lectures from guest speakers and clinicians on a variety of topics relating to health inequity and/or the design process including: Health Inequity in the Emergency Room, the Design Process, Empathy in Design, Ethics in Engineering Design, Ensuring Diversity in Clinical Trials, Social Justice, and Entrepreneurship. The course also included discussions on case studies in ethics with faculty mentors and a design project utilizing send-home Arduino kits to build biosensors. Freshmen had periodic individual and team deliverables, finishing with a prototype and oral presentation. Upperclassmen mentoring was an essential component of the course, with at least one lab manager assigned to each freshmen team of five students. Anonymous end-of-semester surveys indicate that 98% of students strongly agree (60%) or agree (38%) that: *"The Health Inequity project helped me to understand both an injustice within our society and how to apply the design process to solve a need."* Our results, derived from both survey data and students' comments, indicated that the course raised students' consciousness of the issue of health inequity. The team aspect of the project, especially in an online freshmen class taught during a pandemic, made students feel engaged with their classmates by discussing and developing solutions for an issue they felt passionate about improving. Emphasizing the importance of ethics in an introductory freshmen engineering course provides a foundation for designing with empathy.

Introduction – definition and examples of health inequity

"*Health inequities are differences in health status or in the distribution of health resources between different population groups, arising from the social conditions in which people are born, grow, live, work and age. Health inequities are unfair and could be reduced by the right mix of government policies*" [1].

Health inequity has been an issue for centuries, and as noted by Martin Luther King, Jr., *"Of all the forms of inequality, injustice in healthcare is the most shocking and inhumane"*

Freshmen in biomedical engineering were given the above World Health Organization (WHO) definition of Health Inequity, along with multiple examples during their first lecture. The goal of the course is to develop empathy and passion in freshmen engineering students, which was particularly challenging during the COVID-19 pandemic when freshman were studying alone at home. Teaching students the importance of empathy in design requires more than just a lecture. We required students to independently research health inequities so that they would understand how these could lead to health care disparities [2].

We used published data to provide numerous examples of health inequity, including differences in life expectancy in wealthy versus low-income countries, lack of sanitation, under-five

childhood mortality rate, cardiovascular disease, and mental health access leading to significant differences in suicide rates. We also provided data within the US to demonstrate the disparity from one county to another [1], [3]. The COVID-19 pandemic has deepened these inequalities, leaving some communities devastated by the pandemic, while other neighborhoods have been impacted much less [4], [5], and [6]. The pandemic also exacerbated inequities among our students, including pandemic related issues such as disparities in reliable internet access, lack of a quiet place to work, financial security, health concerns, and child care for younger siblings [7], [8].

Using the Design Process to Solve a Health Inequity Issue

Our objective was to teach students the steps required to solve health inequity issues by using the design process.

While we provided multiple examples of health inequity throughout the course, we focused the first class on maternal mortality, which can vary a hundred-fold around the world [9]. Within the US, the mortality of African American and Hispanic infants and mothers is significantly higher than their white counterparts [10]. Data from the Center for Disease Control (CDC) indicate that the maternal mortality rate has, in fact, increased over the last twenty years. A non-Hispanic black woman is 243% more likely to die from pregnancy or childbirth-related causes than a white woman. Solving such a huge injustice requires systematic procedures for clinician training, data collection, and analysis. The California Maternal Quality Care Collaborative [11] applied a systems engineering approach to solving this problem and has made significant improvements compared to other states. Providing an example of both a health disparity and a feasible solution helps students realize that even the most challenging health inequity issues have potential answers.

Biomedical engineering is an ever-changing field shaped by ethical issues, such as health inequity. Previous studies have demonstrated the value of tackling ill-structured and ever-changing societal challenges, such as health inequity, by working in teams [12]. The collaborative environment encourages innovative ideas and fosters teamwork, utilizing the skills of individual students. Facing the challenges of today requires practice solving team-based problems so that freshmen gain not only design, but also personal and professional skills, early in their career [13]. Integrating core engineering knowledge in a mathematical modeling and design course, while concurrently building a foundation in empathy, a critical design skill, prepares students to solve real-world problems [14].

Methods – the Health Inequity Design Challenge – how can we solve this as engineers?

Biomedical Engineering and Design is an introductory two-credit fall semester course. Freshmen (n=111) worked together in twenty-seven teams, with four to five students per team, to research examples of health inequity. The course met one day per week, on Thursdays, for a one-hour class lecture on Zoom and a two-hour session in small groups on MS Teams, where each team had a private channel. MS Teams allowed the twenty-seven groups to work synchronously and asynchronously, posting documents, links to references, videos, and chats as needed. This

flexibility was necessary as our students were located all over the world. Each team had at least one upperclassmen lab manager and a teaching assistant to guide them.

The Health Inequity Design Challenge was one of four course modules. The other three modules included developing a mathematical model of Human Efficiency, a mathematical and circuit model of the Cardiovascular System, and building an Arduino Temperature Sensor and a team-selected Arduino-based Biosensor. The other modules each ran a few weeks, consecutively, while the Health Inequity Design Challenge ran continuously throughout the semester. This arrangement provided the student teams with an engineering-based module each week and a design-based module. Freshmen were graded on both individual assignments (25%) and team deliverables (75%) for each of the modules. Most weeks, students were required to complete an individual assignment, such as taking a quiz, prior to meeting as a team. This method ensured that the freshmen were prepared to contribute during their two-hour team meetings each week. We allowed freshmen unlimited submissions for the quizzes, but they were required to earn a grade of 80% in order to obtain credit for completion. Each of the four modules also required an individual post-module reflection and a peer review in which students rated themselves and their teammates.

Teams were provided resources and guidance through a series of online videos and posted material on the design process. Upper classmen mentoring was a critical aspect of the support system [17], [18]. Not only were teams mentored during their Thursday sessions, each student was also emailed at least twice during the week to check if there were follow-up questions and to remind students about upcoming deadlines. Peer-instruction was an essential component of the project since these topics were cutting-edge. Freshmen needed to educate each other on the details of their subject and bring the team up-to-speed on the selected issue. The team aspect of the project, especially in an online freshmen class taught during a pandemic, made students feel engaged with their classmates by discussing and developing solutions for an issue they felt passionate about improving [13].

Due to the stress of the pandemic, and the fact that all of the students were remote, we felt soliciting regular and routine student feedback was critical for successful adaptation to an online course. Students were required to complete three anonymous surveys at the two-week, mid-term, and conclusion of the semester. The four module reflections and four peer reviews also provided crucial information. The frequent surveys, module reflections, and peer reviews provided timely feedback from the freshmen on their experience in the course [19], [20]. This allowed faculty and teaching assistants to immediately adjust due dates and requirements as needed during the pandemic, occasionally postponing deadlines for some deliverables by a week to allow an extra in-person Thursday session.

Health Inequity Design Challenge Objectives and Weekly Deliverables

The learning objectives for the Health Inequity Design Challenge module are listed below. Students will be able to:

- Define healthy inequity and identify a health inequity issue
- Use the university library resources to acquire data on health inequity
- Analyze and interpret data

- Apply the engineering design process
- Communicate effectively through written and oral presentations
- Recognize ethical and professional responsibilities
- Function effectively on a team

The learning objectives align with the Accreditation Board for Engineering and Technology (ABET) Student Outcomes [21]. The week-by-week list of deliverables for the Health Inequity Design Challenge are posted in Table 1 below.

Table -1 Health Inequity Design Challenge Deliverables

Week	Assignment	Individual/team submission
1	Complete online courses on Human Subjects Research, Lab Safety, Responsible Conduct of Research	individual
2	Post five examples of health care inequity, provide references Two-week anonymous course survey - identify student needs due to the pandemic	individual
3	During section, teams discuss all 20-25 potential areas of health inequity and choose top five for more research (with references)	team
4	Choose one of the five health inequity examples to focus on during semester, provide additional references	team
5	Write Needs Statement for Health Inequity Project: what is the medical problem (increased disease rates, death rates), who is impacted (ethnic group, sex, age, etc.), how (quality of life, financial impact), where (specific country, urban/rural, etc.), and most importantly, why should we care about this issue (empathy)	team
6	Discuss potential solutions and design criteria Propose three potential solutions to the team Needs Statement	team
7	Discuss *Case Studies in Ethics* [15, 16] with team and advisor, post reflection	team
7	Mid-semester anonymous survey - identify student needs due to the pandemic	individual
8	Two minute elevator pitch on Needs Statement and three potential solutions. Seven teams present in an hour using Zoom. Family and friends invited.	team
9	Develop table with design criteria (“must have” and “optional”) Justify “best solution” for stated design criteria.	team
10	Storyboard, prototype, and testing of final design as much as possible	team
11	Continued project work	team
12	Post draft slides for final presentation, practice timing of oral presentation	team
13	Final Oral Presentation: Each of the five students on the team must present part of the 6-7 minute presentation. Seven teams present in an hour using Zoom. Family and friends invited.	individual and team
13	Peer review (rank self and teammates on project effort from 1=best to 5=no work) Health Inequity Design Challenge module reflection	individual
14	Anonymous survey (credit for completion)	individual

In addition to the introductory lectures on Health Inequity, guest speakers provided insight on the design process, social justice, diversity in clinical trials, and other areas of interest to freshmen in biomedical engineering through interactive ethics discussions. For the opening class, a clinician discussed health inequity within the emergency room, providing multiple examples in addition to the disparities in incidence and death rate from COVID-19. A list of lecture topics relating to the module on the Health Inequity Design Challenge is provided in Table 2. The online course format enabled “visiting” guest speakers from across the country to share their experiences with our freshmen. A number of alumni, including a Forbes “30 under 30” entrepreneur, an award

winning non-profit founder and CEO, and a published researcher in the field of health inequity gave inspiring talks.

Table 2 - Freshmen Guest Speaker Topics on Health Inequity and/or Design

Topic of Discussion
Clinician Discussion on Health Inequity in the Emergency Room
Introduction to the Design Challenge in Health Inequity
Optimizing the Library Resources
Introduction to the Design Process
Empathy in Design
Writing a Needs Statement
Ethics: Lecture and Case Study Discussion
Ensuring Diversity in Clinical Trails
Social Justice: Starting and directing a non-profit organization
Entrepreneurship: Starting your own healthcare company

Role of Teaching Assistants and Lab managers

Teaching assistants (TAs) and lab managers have always been an essential component of the success of this course and their dedication was vital in teaching online. The primary role of both the TAs and lab managers was to ensure that every freshman was participating each Thursday and was provided the assistance needed to complete each module. TAs and lab managers were required to complete online Family Educational Rights and Privacy Act (FERPA) training prior to the start of the semester. While the TAs were paid for their assistance, the upperclassmen received two-credits for mentoring and supporting the freshmen teams. There were eight teaching assistants, each responsible for grading three to five teams, and thirty lab managers. The small student/mentor ratio provided each freshmen the individual attention they needed to succeed. All TAs and lab managers were required to complete each of the modules before meeting their freshmen teams. The course director met with the TAs and lab managers prior to the start of the course and before each of the modules opened to ensure that everyone was prepared to answer the freshmen's questions.

Assessments

The final course grade was based on individual (25%) and team assignments (75%). The individual assignments for this project involved completing online courses in Human Subjects Research and Responsible Conduct of Research in addition to the school-required lab safety training.

The Health Inequity Project was worth 25% of the student's total grade for the course. The team deliverables for this project included:

i. Identify five potential projects and choose final project (5%)
ii. Develop Needs Statement and three potential solutions (5%)
iii. Elevator Pitch listing design criteria (Two-minutes) (5%)
iv. Final Presentation (10%)

Each freshman was required to research and submit five examples of health inequity, with references. Consequently, a team of four to five students discussed up to twenty-five different

topics. Even with overlap, the freshmen became aware of the enormity of the issue of health inequity due to gender, age, and racial bias, geographic location, and financial means. Using MS Teams, each freshmen, guided by a lab manager, contributed to the discussion and helped finalize a top five list of priorities. Further research and discussions allowed the team to finalize their topic and develop a Needs Statement.

The freshmen teams worked with their lab managers and TAs prior to each submission or presentation to ensure that the team met the standards posted in the rubric for each deliverable. Needs statements were discussed and reworded, design criteria were evaluated, and presentations were timed, to provide the freshmen feedback prior to being evaluated on their final product. The team deliverables were intended to be achievements, not stressful grading experiences. We took advantage of the virtual delivery and invited parents, high school teachers, and friends to join us during the teams' presentations. We received Internal Review Board (IRB) approval to share the class results in publications and presentations.

Results

We first incorporated a Health Inequity Design Challenge in our freshmen course in spring 2020, prior to the start of the pandemic. The project was embraced by the freshmen and subsequently updated to an online format for fall 2020. It is important to note that many projects focused on issues which were exacerbated by the pandemic, such as access to mental health treatment, monitoring cholesterol or diabetes at home, "food deserts" in many urban areas, and availability/ access to telemedicine. Some teams used their Arduino kits to develop a prototype, such as a building population counter to provide instantaneous classroom density data to protect immune-compromised students and faculty. Other teams ordered supplies through the design center to perform pre-approved experiments at home to test their prototype. Many of the teams developed an app due to their limited access to supplies. For some, this design challenge was personal as they had experienced a health inequity personally or in their family and, as such, they truly wished to work on a viable solution. A complete list of the topics researched by the freshmen teams is provided in Table 3.

Table 3 – Health Inequity Design Challenge Topics

Pregnancy-related mortality in African American women
Improving sterilization in Dharavi, Mumbai
Cognitive impairment and social isolation in ICU patients
Tackling chronic illness through telemedicine
Treatment of diabetes for people experiencing homelessness
Malaria in low-income countries
Systematic Pandemic Anti-Crowd Engineering Solution (SPACES)
Diversity in clinical trials
Diagnosis and treatment of sepsis in developing countries
Improving the high cholesterol levels of America's urban welfare recipients
Mental Health Care: ALOE – Awareness towards Loving Our Emotions
Colorectal cancer in Mississippi's African American residents

Inequities in access to mental healthcare treatment
Building better fitting prosthetics
A novel solution for at-home sexually transmitted infection testing
Fighting food deserts
Disparity across sexes in heart attack treatment and diagnosis
Underrepresentation of African Americans in cancer clinical trials
Water pollution solution
Down syndrome patients' clinical experience
Diagnosing acute respiratory infections
Impact of sepsis across geographic regions
Oral healthcare inequities

We evaluated the results of the course based upon our ***objective to teach students the steps required to solve health inequity issues by using the design process.*** Evaluating the success of the Health Inequity Design Challenge required reviewing the course content, individual assessments, and teams' results. The engineering-based course content (videos and handouts on the mathematical models of Human Efficiency, the Cardiovascular System, and the Arduino projects) was prepared and posted on Blackboard prior to the start of the course. Based on anonymous surveys, 86% of students felt the online material was clear to understand and they were able to complete their individual assignments successfully. The live lectures on Zoom discussed health inequity and the design process. A Likert Scale, in which 95% of students strongly agreed (54%) or agreed (41%), was used to evaluate whether "*The Thursday noon talks gave me a background in design, ethics, and health inequity. They also illustrated numerous career options for students in BME and have increased my excitement for the field*".

The survey data indicated that 98% of the freshmen believed the project helped them to understand both an injustice within society and how to apply the design process to solve a need. They also felt the deliverables for the Health Inequity project (elevator pitch, design criteria, final presentation) required both teamwork and professional skills.

The guest speakers had a powerful impact on the freshmen. Speakers included an ER clinician who treated a child seriously ill from a neglected tooth, an entrepreneur motivated by his mother's cancer diagnosis to develop a start-up in digital pathology, a faculty member who developed a mathematical model for accurately diagnosing sepsis, and a researcher sharing data from her work on the lack of diversity in clinical trials for prostate cancer treatment, particularly among African American and Hispanic patients. A lecture on "Designing with Empathy" stressed the importance of understanding your client and meeting their needs. An engineering solution which is appropriate in one country might not work in another. The Thursday noon lectures allowed students to ask questions or send follow-up emails to obtain more information and 95% agreed that "*the Thursday noon lectures gave me a background in design, ethics, and health inequity*".

In addition to learning about health inequity and the design process, we were concerned with the freshmen's mental health, their ability to integrate into the Biomedical Engineering department, and social interaction with their peers in an online environment. We felt it was even more

important during the pandemic to increase opportunities for collaborative activities. Two thirds (67%) of freshmen strongly agreed and another 28% agreed, a total of 95%, that "*my team of freshmen classmates have not only helped me to learn but have made learning fun and more relaxed*". The freshmen survey results are summarized in Figure 1.

The questions posed to the freshmen in the end-of-semester survey indicated that students felt they met the course objectives, had the support they needed (both online and through mentoring), and were satisfied with the grading for the course. A small percentage of students (less than 10%) did not agree that the peer reviews, reflections or online materials were satisfactory. For every other aspect of the course, the freshmen were very enthusiastic. Representative comments from the freshmen about the course and the project are posted in Table 4.

Table 4 – Student comments

This was my favorite class! I felt engaged in the content and there was always a new facet of inequities and design to learn about. I also felt incredibly connected with my team, which really helped me to stay on top of my work.
The best part of this class was probably either the health inequity project or the cardiovascular lab. Our team became very close through the health inequity project, and several of us found new areas of interest we hadn't thought of before.
I really liked the Health Inequity project. It was really fun working with my teammates to research about the health inequity issue that we picked and brainstorm feasible solutions.
I liked the guest lectures. They were definitely the best part of the class. I also thought the health inequity project was fun.
Given the online format, having the lab group do Zoom meetings and have a group chat outside of class somewhat simulated the experience of studying and doing homework with friends that was really hard to find otherwise.
I really enjoyed the health inequity project and being able to properly present in front of the class, it helped sharpen my design/presentation skills.
I think the best part was working with my teammates on the projects. With this virtual semester, I barely ever actually met anybody in my classes, besides just maybe seeing their face during a lecture. This class was much more fun because I actually interacted with other people.
I really enjoyed having a consistent lab group that worked together on assignments all semester and met outside of class. This structure really helped me be able to get my work done significantly more effectively/efficiently than in any of my other classes for which assignments were completely individual.

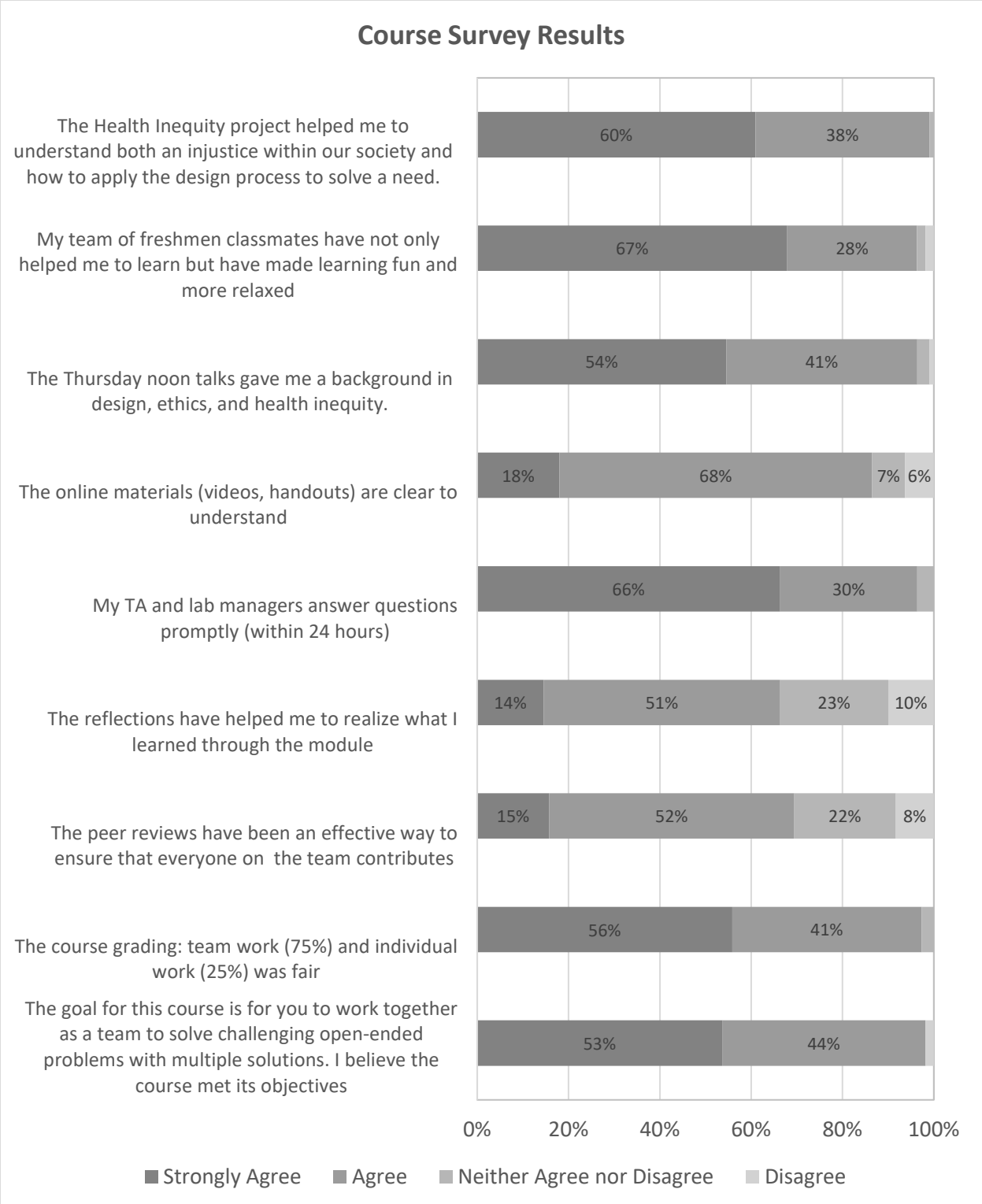

Figure 1: The end-of-semester survey queried freshmen on their perceptions of the course using a Likert Scale (data values of less than 5% have been removed from the bar graphs for clarity).

The quantity and quality of the teaching assistants and lab managers played a crucial role in the success of the course. TAs and lab managers provided essential mentoring and support, not only

on Thursdays but throughout the week. Based on a survey given at two weeks, over 90% of freshmen strongly agreed (36%) or agreed (54%) that they felt comfortable contacting their TA and/or lab manager. This percentage increased to 98% (strongly agree: 68% and agreed: 30%) by the end of the semester. The TA and lab manager survey results at the two-week, mid-semester, and end-of-semester time points are shown in Figure 2.

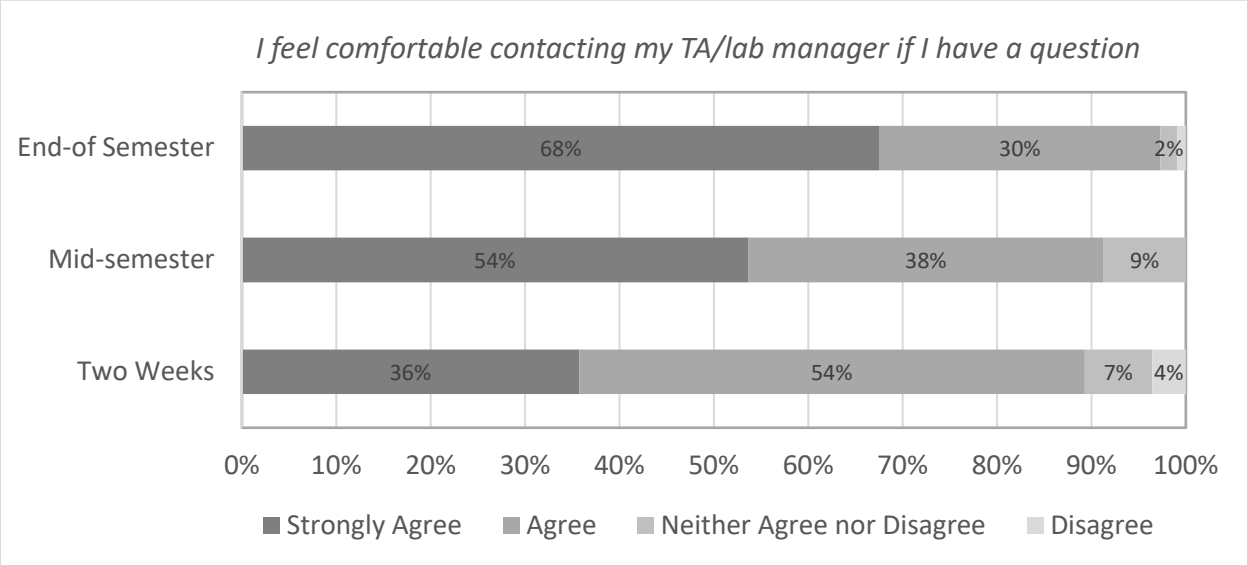

Figure 2: Freshmen were surveyed after two-weeks, seven weeks, and at the completion of the semester (fourteen weeks) on how well their TAs and lab managers were succeeding as mentors. At two weeks, over 90% of freshmen agreed that they were comfortable asking questions. The percentage of freshmen who strongly agreed with this statement increased throughout the semester to 68%. By the end of the semester, 98% of the freshmen felt comfortable contacting their TA or lab manager.

Limitations

Teaching a freshmen course online has its limitations. Students were located all over the world, in different time zones, and yet they were expected to participate in synchronous activities. The freshmen could enroll in their choice of two-hour section meeting times on Thursdays ranging from 8 AM until 6 PM on MS Teams which helped with some of the time differences. Although the Thursday noon lectures accommodated most time zones, we still recorded all lectures for convenience. Many students had internet limitations which did not permit using a video while meeting. Some students, including one TA, were located outside of the US and had problems with MS Teams, resulting in a switch to Zoom meetings.

Expecting freshmen to solve an issue in health inequity is quite ambitious. The freshmen had limited supplies – an Arduino kit, circuit board, and whatever could be inexpensively and quickly ordered and mailed to their homes. Consequently, most teams focused on developing an app to address their chosen issue. Students were asked to develop and test their projects as much as possible, but the lack of supplies combined with the pandemic severely limited the ability of any of the teams demonstrate more than a proof-of-concept. Teams who were interested in continuing to work on their projects were encouraged to enroll in a follow-up course resulting in participation in a Business Plan Competition at the end of the spring semester.

Quantitative data on student course achievement included completion of the university's online courses in Basic Human Subjects Research and Responsible Conduct of Research, and individual quiz and final exam scores based on the four modules. It is difficult, however, to evaluate success in teaching design and empathy of a health inequity issue through quantitative measures. While our survey data indicates we have been successful, follow-up analysis of these students in future classes will provide useful feedback.

Discussion

The success of an online freshmen course taught during a pandemic requires careful planning to ensure that students have the resources and support they need to succeed. Pre-recorded lectures with critical course content, team-based projects, upperclassmen mentoring, and synchronous sessions ensured that freshmen were actively engaged each week. Guest lectures, followed by question and answer sessions, not only provided crucial information, but inspired a number of groups in choosing their project topics. The combination of collaborative, project-based learning, motivating weekly lectures, and careful mentoring ensured a supportive environment.
The two-hour sessions on Thursdays were devoted to peer-based active learning guided by upper classmen lab managers and TAs. Peer and upperclassmen mentoring have both been shown to be highly effective in undergraduate education [22], [23], particularly in teaching design [17].

Based on the end-of-semester comments, the freshmen were enthusiastic about their chosen projects, not only for the Health Inequity Design Challenge but also for the Arduino sensor project. Their success, despite starting their freshmen year online, was not surprising given previous research indicating that freshmen can thrive attempting ill-defined problems, such as a health inequity issue [12], [24]. Allowing freshmen to choose their own team-based projects gives students a head-start in developing the personal, interpersonal, intellectual, and professional skills needed for a successful career [13]. The advantage of the online format was that students could invite their family, friends, and even high school teachers to their presentations. While only a small number of freshmen took advantage of this option, the guests who came were very enthusiastic and supportive.

Our goal was to introduce students to the design process, develop an awareness of a serious ethical issue – health inequity, and instill professional skills in a relaxed, friendly, environment. Given that this course was taught during a pandemic, we were concerned about the stress that many of our students faced at home. The surveys, peer reviews, and reflections provided the frequent feedback needed to adjust the course deadlines and offer additional resources.

Freshmen enthusiastically embraced the opportunity to solve a design challenge in health inequity. They enjoyed working in teams, made friends even in the virtual environment, and gained professional skills. Using the design process to develop a Needs Statement, brainstorm solutions, rank design criteria, and develop a prototype empowered freshmen to envision potential solutions to some of the most challenging issues facing mankind. Post-pandemic offerings of this course, in-person, should allow students to progress even further in the design process.

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