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An Approach to Integrating Health Disparities within Undergraduate Biomedical Engineering Education

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Abstract

Health disparities are preventable differences in the incidence, prevalence and burden of disease among communities targeted by gender, geographic location, ethnicity and/or socio-economic status. While biomedical research has identified partial origin(s) of divergent burden and impact of disease, the innovation needed to eradicate health disparities in the United States requires unique engagement from biomedical engineers. Increasing awareness of the prevalence and consequences of health disparities is particularly attractive to today's undergraduates, who have undauntedly challenged paradigms believed to foster inequality. Here, the Department of Biomedical Engineering at The City College of New York (CCNY) has leveraged its historical mission of access-and-excellence to integrate the study of health disparities into undergraduate BME curricula. This article describes our novel approach in a multiyear study that: (i) Integrated health disparities modules at all levels of the required undergraduate BME curriculum; (ii) Developed opportunities to include impacts of health disparities into undergraduate BME research projects and mentored High School summer STEM training; and (iii) Established health disparities-based challenges as BME capstone design and/or independent entrepreneurship projects. Results illustrate the rising awareness of health disparities among the youngest BMEs-to-be, as well as abundant undergraduate desire to integrate health disparities within BME education and training.

Keywords

Curricular modules; Capstone design; Entrepreneurship; Undergraduate research; High school mentoring; Minority Serving Institution (MSI)

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INTRODUCTION

The continued growth of research and educational programs in Biomedical Engineering (BME) have bridged BME with science and technology policy, public health initiatives and community-based challenges.^{13,20,23} A new and distinct challenge with mounting BME interest and participation is Health Disparities, i.e. preventable differences in the incidence, prevalence, mortality and burden of disease on communities targeted by factors such as gender, geographic location, ethnicity and/or socio-economic status. Applications of BME technologies, such as bioinformatics, have illustrated divergent burden of disease across the United States, but more poignantly also uncovered disturbing and puzzling health disparities. For instance, rural Americans suffer disproportionately elevated obesity rates,²⁶ degenerative vision loss unduly affects residents of the Southern USA¹⁷ and cardiovascular disease is more likely to result in death for American women than men.²⁴ For such US-based disparities, conventional biomedical interventions by specialized experts have begun to fail; simultaneously dismissed by residents as merely community-placed rather than community-based and raising the ire of biomedical professionals and the communities in which they live and/or serve.^{11,20} These changing community dynamics have created a critical need for alternative strategies to address health disparities challenges that can be powerfully met by biomedical engineering *via* more encompassing undergraduate training.³

The numbers of government-funded, peer-reviewed publications that have examined the impact, consequences and causes of health disparities in the USA have steadily increased in the past decade, as per data obtained from database searches shown in Fig. 1. These records illustrate persistent scholarship from social science and clinical departments in health disparities-based study, but display a modest, albeit growing, contribution of researchers from Science, Technology, Engineering and Math (STEM) fields. The BME advances needed to eliminate health disparities requires unconventional engagement and technical opportunities for STEM researchers to comprehensively evaluate this unusual community-based challenge. The study of health disparities in the context of BME has acute appeal to today's undergraduates, who have undauntedly challenged social paradigms believed to foster inequality and are newly-attracted by the established concept of praxis, i.e. wherein engineers strive to transform existing and future technologies into community-based interventions and solutions.¹⁶ Introducing undergraduates to biomedical areas of communal need that can be remedied *via* engineering technology will empower BMEs to confront the pervasiveness of health disparities in the USA and will also expand the knowledge base of undergraduates who seek employment in federal agencies, biomedical/clinical technology companies and start-up ventures with community-based platforms.

Recent studies have suggested that students are more likely to become engaged in health disparities research if they are associated with communities that suffer disproportionately from inequities in medical care.^{3,16,22} Thus, the current project has leveraged the historical mission of access-and-excellence²² at The City College of New York (CCNY) to incentivize the integration of health disparities into undergraduate curricula. CCNY is the City College flagship campus of the City University of New York (CUNY), which is comprised of 24 campuses within New York City (community colleges to doctorate-awarding colleges). Located in Northern Manhattan, the Harlem-based CCNY campus sustained an enrollment

of 15,000 undergraduates and 5,000 graduate students during the 2016–2017 academic year. The CCNY Grove School of Engineering (GSOE) is the only ABET-accredited, public engineering school in New York City, with approximately 3000 undergraduates working towards Bachelor of Engineering degrees (B.E.) and 400+ graduate students working towards Master's and Doctoral degrees in engineering. Further, CCNY is a Minority Serving Institution (MSI), defined by the National Science Foundation (NSF) as a school of higher education in which half or more of enrolled students identify as African-American, Hispanic-American, Native-American or Pacific Islander.¹⁴ Singularly, CCNY is an MSI that is simultaneously a Hispanic Serving Institution (HSI) and a Black Serving, non-Historically Black College or University (non-HBCU), i.e. a college where at least a quarter of students are Hispanic-American or African-American, respectively. These distinctions highlight the unique diversity of CCNY, whose comparable student enrollment from all major US demographic groups make the college an excellent pioneering site for the integration of health disparities into BME undergraduate education.^{14,26}

The current article describes a 4-year educational project in the CCNY Department of Biomedical Engineering that introduced BME undergraduates to the impacts of health disparities *via* didactic educational training, undergraduate research and independent design projects. As shown in Fig. 2, the project combined multifaceted educational activities to increase awareness by: (i) Integrating health disparities modules within all 4 years of the required BME core curriculum; (ii) Developing opportunities to include impacts of health disparities into undergraduate research projects and mentored High School summer STEM training; and (iii) Establishing health disparities-based challenges as BME capstone design and/or independent entrepreneurship projects.

MATERIALS AND METHODS

A mixed-methods approach was used to document and assess health disparities-based initiatives and student performance data.

BME Undergraduate Coursework (Years 1, 2, 3)

- *Lectures* Courses targeted for integration of health disparities research included lectures presented by one BME faculty and one non-BME faculty with primary research focus in health disparities (e.g. community health, social sciences). These tandem lectures were presented in 60- to 90-min time increments for one week of a 14-week-long semester. Courses that included a longer module in health disparities incorporated 3 weeks of lectures in a 14-week-long semester.
- *Case Studies* Guest lectures introduced BME undergraduates to health disparities research and impact using widely-cited case studies. Lecture materials included: (A) High school-level review of the STEM underlying each health issue discussed; (B) 2–3 links to NIH- and NSF-funded educational web sites relevant to the science discussed; (C) 1–2 newspaper articles (e.g. *New York Times*) addressing the community challenge; and (D) 1 peer-reviewed engineering article per case study. All materials were available *via* course website and faculty webpage.

- *Assignments* Students were required to provide 1000-word technical summaries of case studies, create a 3-min podcast to serve as a public service announcement via social media and class website, and/or a 15-min oral class presentation, group or individual, of a health disparity of interest.

Undergraduate Mentoring of High School Summer Researchers (Years 3, 4)

A summer course entitled, *Experimental Research in Engineering (ERE)*, was developed to enable BME undergraduate researchers to train High School (HS) students within the context of their own BME research projects by integrated health disparities-based study. HS students were part of the CCNY Summer STEM Institute (SSI), a rigorous, 6-week pre-college program offered free of charge to area students in grades 9 through 12.

BME Independent Undergraduate Projects (Years 3, 4+)

- *Design Projects* Students in the BME 2-semester capstone design sequence are arranged into 4-person teams based on project interest. Each project is sponsored by clinician(s) who have previously developed an engineering, ABET-appropriate design challenge with BME design faculty. Teams must demonstrate a working prototype alongside a project poster describing the technical aspects and community-based impacts of their designs at our annual BME Day, an open forum with over 200 engineering students and faculty held each May.
- *Entrepreneurship Competitions* The Zahn Innovation Center hosts annual entrepreneurship competitions that develop CCNY student innovations into products by incubating the most promising technology startups and social impact ventures. The Zahn Center offers cash awards (\$10K–\$100K) in four categories: (i) Kaylie Prize in Prototyping; (ii) Zahn Prize in Software Apps; (iii) Zahn Prize in Sustainable Social Ventures; and (iv) Standard Charter Prize for Women in Technology. Participants enroll in a 15-week product boot camp based on the Lean Startup methodology⁶ and winners are selected by external panels of entrepreneurs and venture capitalists to launch their startup in the Zahn summer accelerator.
- *CCNY-Memorial Sloan Kettering Partnership (MSK)* This NIH-funded center supports collaborative biomedical research to implement joint education and training opportunities in medically-underserved communities and address needs of minority students and scientists at critical junctures along the career development path.^{1,7,12} The current project leveraged these collaborative efforts to raise awareness of health disparities in BME undergraduates, programmatically, via coursework and undergraduate opportunities.

Assessment Methods

This project gathered data from undergraduate performance using multiple sources.

- *Course Assignments* Each course targeted in this study provided students with opportunities to select a health disparities-based topic for 1–2 graded assignments. The numbers of students who selected health disparities for these

so-called student choice assignments were measured for 4–6 consecutive course offerings (at least 4 years).

- *Independent projects* These data were measured *via*: (A) Student selection of health disparities challenges as capstone design projects; and (B) Participation in entrepreneurship projects with health disparities impacts *via* the Zahn Center each year.
- *Student applications for Participation* The numbers of BME students who applied and were selected/-trained to become undergraduate research mentors for HS researchers as part of the Summer STEM Institute each year.

RESULTS

This project used a multifaceted approach to develop health disparities-based challenges that can also function as technical BME coursework modules and design projects.

Biomedical Engineering at CCNY: Pioneers for Community-Based Challenges

The CCNY Department of Biomedical Engineering was established with the unique goal of developing an urban model for engineering education that bridged MSIs with private medical centers. The BME Department flourished from the New York Center for Biomedical Engineering (NYCBE), a consortium created to facilitate interdisciplinary biomedical research between investigators at area medical centers and faculty at CCNY, the area's sole, public engineering college. As seen in Fig. 3, the current NYCBE consists of 8 primary hospital partners, each of which provides research and training opportunities for CCNY undergraduates in their facilities, co-mentors CCNY graduate theses and engages in NIH- and NSF-funded research and/or design projects jointly with CCNY investigators. CCNY's dedication to upholding diversity alongside academic excellence *via* the NYCBE has led to several unique awards and distinctions, including multiple leadership positions and diversity awards from the national Biomedical Engineering Society (BMES),^{2,28} as well as inaugural educational funding from the NIH and, most recently, economic recognition as a national leader in alumni upward mobility.⁴ The data in Fig. 3 illustrate that CCNY recently celebrated its first decade of baccalaureate degrees awarded in Biomedical Engineering, with growth from an inaugural class of 10 students to the current cohort of over 40 B.E. graduates. That nearly a third of total alumni identify with groups underrepresented in STEM^{9,10,13} highlight the remarkable diversity of CCNY, which makes the college an ideal pioneer for the integration of community-based challenges within BME education.

Health Disparities-Based Study within the BME Undergraduate Curriculum

The first component of this project integrated health disparities data, research and its BME implications into didactic undergraduate courses in Year 1, Year 2, Year 3 and Year 4 of the BME core curriculum. As shown in Table 1, the courses selected for this project were required for BME majors, but many were also open to other engineering majors with completed co-/pre-requisites and instructor permission. For brevity, this article will only discuss the addition of health disparities in one course per sequence, as health disparities were introduced in a very similar manner across courses within the same programmatic year.

In Year 1, students enrolled in *Introduction to Biomedical Engineering (BME101)* were introduced to health disparities *via* one week's worth of lecture material in the context of the visual system. A case study in visual health was chosen for two reasons. First, the workings of sensory perception are of fundamental interest to virtually all students. Second, because the case study illustrates that while vision loss is the primary fear of those of working age, multiple disparities make it, sadly, the largest cause of disability among cohorts of working Americans. Lectures, first, reviewed elementary physics to re-introduce first year students to functions and operation of the eye, and second, summarized current CCNY research in the visual system in the context of BME applications.^{21,27} Last, lectures incorporated case studies to highlight the disparate burden of vision loss across geographical regions of the USA²⁹ and within particular age groups.²⁵ A podcast of these coalesced topics was made available *via* the course website and faculty webpage. Students interested in these so-called 'health disparities-integrated' BME topics were able to select it for one of the student-chosen, 1000-word technical reports used in course grading.

In Year 2, honors students enrolled in *Science and Technology in New York (MHC203)*, were introduced to health disparities *via* a 3-week long module that focused on three case studies: (i) Cardiovascular Disease, the largest current cause of death in the USA²⁴; (ii) Obesity, the largest health epidemic currently facing the USA²⁶; and (iii) Vision Loss, the largest current disability fear of working Americans.¹⁷ All case studies were presented *via* the health disparities-integrated BME lecture style described above, but assignments required increased technical knowledge. Here, 1000-word technical reports from student groups were required to discuss the underlying science for each disease, and individual students needed to prepare a 3-min podcast on a health disparity of choice. Note that health disparities in BME220 is in progress at time of publication as per the * in Table 1.

In Year 3, students were exposed to impacts of health disparities in *Experimental Methods in Biomedical Engineering (BME310)*. The course is an introductory wet laboratory examining flow through porous media, culture of mammalian cells, fluorescent staining and imaging of cells and electrophoretic separations of cell lysates. In this more advanced course, health disparities was introduced in one full laboratory module by performing fluorescent staining of different cell lines that included HeLa cells.¹² Lectures included discussion of book excerpts from *The Immortal Life of Henrietta Lacks*, the origin of HeLa cells, and in recent years the television film about Ms. Lacks.¹⁵ For assignments, students were required to incorporate a 300-word section in their laboratory reports that discussed the impact and BME ethics of health disparities on their experiments and on the BME community at large. In addition, students submitted graded assignments on one design project presented by senior BME students (discussed in Year 4) of interest, which included many health disparities projects. Note that health disparities in ENGR300 is in progress at time of publication as per the * in Table 1.

In Year 4 (and Year 4+, if applicable) health disparities was introduced *via* more hands-on design and independent projects based on student interest. As seen in Table 1, health disparities were presented to seniors enrolled in BME Capstone Design as part of a greater scope of community-related BME challenges, which included disabilities, health disparities, global health and rehabilitation. Here, design instructors developed engineering-appropriate

projects with NYCBE clinicians and students were grouped into design teams based on technical interest. In *Senior Design I (BME450)*, students were required to research the background and clinical need of the chosen project as well as generate design specifications for a prototype to be constructed in *Senior Design II (BME460)*. As part of this project, undergraduates were required to write a 500-word section in their group project report that cited peer-reviewed health disparities research relevant to the design project, as well as integrate these data into their monthly project presentations. The extent to which health disparities was integrated into capstone design projects depended upon the nature of the project itself. Regardless, student groups were required to cite at least 2 references in health disparities related to their project in each of 2 reports per semester. Students were additionally presented with health disparities research *via* guest lectures from non-BME faculty once per term. Lastly, many BME undergraduates in their final year (Year 4 or Year 4+) often use capstone projects to participate in the student entrepreneurship activities of the Zahn Innovation Center *via Independent Study (BME591)* or without academic credits merely for the experience *via* Zahn boot camps and incubator workshops.

Metrics of BME Engagement in Health Disparities Coursework

The engagement of BME undergraduates with health disparities integrated into their technical engineering courses was measured after each curricular year. Figure 4 illustrates the increase in the percentages of BME students who selected health disparities-integrated BME topics for didactic coursework, e.g. reports and presentations. As seen, BME student interest in health disparities has risen sharply during the 4–6 years of this project. Student interest in health disparities after Year 1 was assessed *via* the percentage of student choice assignments that included health disparities. Figure 4a demonstrates that student interest in health disparities during the initial project year of 2012 was 22%, but increased dramatically to nearly 80% by the end of the 2016–2017 academic year. After BME Year 2, the number of health disparities challenges selected for student choice assignments similarly rose from 30% to greater than 90% during the project period, as per Fig. 4b. Following BME Year 3, students were required to discuss health disparities as part of laboratory modules, but were additionally offered student choice assignments that included health disparities. As seen in Fig. 4c, the numbers of health disparities-related assignments rose from a modest 17 to 70% in the 2016–2017 academic year.

Undergraduate Research and Mentoring of Summer High School Students

The second component of this project cultivated awareness of health disparities in BME undergraduates by using hands-on projects in undergraduate research and capstone design projects. Here, BME undergraduates engaged in faculty-sponsored research were able to integrate health disparities relevant to their projects *via* mentoring of HS summer student groups.⁸ This integration was performed in partnership with the CCNY Summer STEM Institute (SSI), which administers a free educational program each year to train and retain NYC pre-college students in STEM fields. SSI cohorts have grown from 50 to 175 students over the past 15 years, with annual enrollment of at least 40% underrepresented students. Further, more than three-quarters of overall SSI alumni have progressed through STEM undergraduate programs, while one-quarter have successfully enrolled and/or completed CCNY STEM majors.

A summer course entitled, *Experimental Research in Engineering (ERE)*, enabled BME undergraduate researchers to train high school summer researchers in health disparities-integrated BME projects.⁸ The objective was to engage BME undergraduates in the health disparities aspects of their engineering research, by having them mentor pre-college students in community-based BME projects. Summer research teams were comprised of one BME faculty mentor, one undergraduate research mentor (UGRM) and a group of 3–4 High School Summer Researchers (HSSR). The ERE program was supervised by the faculty mentor who selected UGRM, identified BME laboratory spaces, projects and materials, was the programmatic interface with the SSI and required all parties to obtain a Certificate of Fitness (CoF or C-14) from the Fire Department of New York (FDNY), which trains researchers in government-regulated hazardous waste management. During the 6-week ERE course, UGRM presented a 1-h technical lecture on their BME research topic to the entire group, and provided 3 h of hands-on experimental training to their assigned HSSR group each day. UGRM were additionally responsible for SSI weekly tours of BME laboratories and shared facilities, such as the Nanofabrication Clean Room Facility and Microscopy Imaging Center, and attended weekly, faculty-sponsored workshops in ethics, health disparities, imaging, image processing software and micro-molding techniques alongside HSSR students.^{1,18} Lastly, UGRM tutored their HSSR teams in poster project development, presented at the closing SSI ceremony to 500+ people. As seen in Table 2, each poster described the experimental goal, the experiments performed, a health disparities case study related to the project and conclusions from the summer research data gathered jointly by HSSR and UGRM. These projects enabled UGRM to connect BME research with cell culture, biomaterials and microfluidic systems with the health disparities associated with cell origins and burden of retinal and cardiovascular disease as well as dysfunction in musculoskeletal systems.

Popularity of the ERE program among BME undergraduates is illustrated in Fig. 5, which depicts the increasing numbers of third-year and fourth-year BME undergraduates who applied to be UGRM against the small number that could be selected. Further, successful UGRM career development was evident in the 100% who attended BMES meetings for the first time as a result of the ERE, and/or presented research in BMES health disparities mini symposia.

Capstone and Independent Design Projects

The third and final component of this project was to create health disparities-based technical challenges that met ABET requirements of engineering and capstone design. Table 3 illustrates a representative variety of capstone design projects undertaken with NYCBE clinical partners that featured a core health disparities-based challenge. As seen, design groups have developed software, shareware and phone apps as well as manufactured hardware to address the technical BME needs of clinicians while highlighting the health disparities their technologies can address.

The interest of graduating students (Year 4, Year 4+) in health disparities was evident in the steady increase in community-based capstone design projects in recent years. As seen in Fig. 5, community-based projects constituted 100% of capstone design in the 2015–2016 and the

2016–2017 academic years, with health disparities-based challenges increasing steadily from 10 to 44%. Additionally, the data in Fig. 5 illustrate the increasing numbers of BME students who have joined entrepreneur workshops and design teams that develop community-based projects *via* the Zahn Innovation Center. As seen, BME students comprised over half of competing teams since the center was established in 2012. Further, BME teams have won top prizes in 4 of the last 5 years, with a third of these projects related to global health or health disparities.

DISCUSSION

Pioneering Integration of Health Disparities into Biomedical Engineering

Growth of BME undergraduate programs across the nation present increased engagement opportunities for health disparities research and awareness. CCNY has been an ideal pioneering site for the educational fusion of Biomedical Engineering and Health Disparities given its heterogeneous MSI student body and NYCBE collaborations with private institutions to increase diversity of thought across all communities. The renewed appeal of praxis to millennial undergraduates highlights how BMEs can use technology (re-)development to address community-based challenges in health disparities as well as for societal impact more broadly. Irrespective of public or private institution, universities can begin introducing health disparities to BME students by collaborating with public health professionals to identify communities of broad appeal within their university body, e.g. first-generation college students, veterans and/or personnel from the armed forces, or students from impoverished backgrounds. Our project suggests that once STEM students begin to question the underpinnings of health disparities that impact their closest communities, many will be motivated to use their skills to help achieve medical parity for all communities.

Knowledge of Health Disparities within Biomedical Engineering Courses

This project cultivated the inclusive critical thinking skills needed to evaluate health disparities-based BME challenges by introducing case studies from the USA with increasing levels of complexity in Year 1 through Year 4 of the BME curriculum. Each lecture and/or course module in health disparities incorporated increased technical BME content per year, from application of statistical methods, to culturing of cells from different sources and developing prototypes/software/apps to aid specific communities. Results illustrate undergraduate interest in health disparities rising over this study, with sustained interest in community-related BME projects by fourth and/or graduating students. The steady increases in disparities student choice projects reflect rising student awareness of health disparities that is bolstered by course(s) content over time.

Progressive selection of health disparities-based projects by BME seniors over time was a meaningful aspect of our project, as numerous BME teams merged these health disparities challenges with entrepreneurship to compete and win competitions of the Zahn Innovation Center. This result illustrates that incorporating health disparities within undergraduate curricula helps broaden the set of data from which students can make engineering decisions to further act upon their innovations. Student development of such capstone challenges greatly bolster awareness of health disparities at our annual BME day, where many first and

second year students often nucleate ideas for independent study and/or design projects after exposure to completed capstone projects. These data highlight that open forum technical discussions can be particularly powerful for community-based projects, where student excitement and word of mouth are key.

Disparities Engagement via BME Undergraduate Research and Summer Mentoring

One of the most unique aspects of this study was the integration of BME undergraduate research mentors (UGRM) with HS summer researchers (HSSR) as part of the Summer STEM Institute (SSI). Our summer *Experimental Research in Engineering* (ERE) course was unique in its development of UGRM as teachers and mentors to train HSSR in hands-on engineering skills needed for BME research. The integration with health disparities helped UGRM evaluate their research projects with a community-based focus and aided UGRM career development *via* new engagement in BMES conferences and graduate school trajectories. Lastly, the SSI research posters strikingly demonstrated successful integration of health disparities with BME research data, and both UGRM and HSSR were proud to publicly present this work to the entire SSI community of 500+. We contend that such dissemination from excited youth to peers and family is the key to increased engagement in health disparities-based study from forthcoming generations of BMEs-to-be.

Lessons Learned and Future Work

This project enjoyed two large successes. First, we raised the collective awareness and knowledge of health disparities in BME cohorts *via* programmatic coursework and public showcasing events (e.g. BME Day, SSI). We note that the lack of a ‘track-based’ curriculum^{5,19} serendipitously helped ease introduction of health disparities to all BME undergraduates and monitoring of interest per BME cohort over time. We maintain that additional integration of coursework modules into every required BME course and funded participation in elective programs (e.g. Zahn Center, ERE) will greatly increase student engagement in health disparities-based BME projects. Second, the BME Department greatly benefitted from collaboration with community and health faculty. Perspectives from public health professionals genuinely ignited BME student interest in community themes, while technical background material slyly incorporated STEM concepts into the education and training of non-majors. Future work will engage graduate students in health disparities using the coursework modules and summer research described here, as well as encourage new cohorts of BME graduate students to discuss potential community-based impacts of their research during group seminars and exam presentations.

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FIGURE 1.

The growing numbers of peer-reviewed publications that examine US-based health disparities. The hashed data indicate the portion of health disparities-based study performed within departments of Science, Technology, Engineering and Mathematics (STEM), while the solid data represent health disparities research from social science, humanities and clinical departments.

FIGURE 2.

Schematic representation of the multifaceted educational activities developed to increase awareness of health disparities in BME undergraduates at The City College of New York (CCNY).

FIGURE 3.

Composition of the New York Center for Biomedical Engineering (NYCBE) consortium with 8 primary research partners, alongside numbers of Bachelor of Engineering degrees (B.E.) awarded in Biomedical Engineering during the department's inaugural decade at CCNY.

FIGURE 4.

Interest of Biomedical Engineering undergraduates in Health Disparities (HD)-based coursework. (a) The percentage of health disparities-based BME projects selected for student choice assignments in Year 1; (b) percentage of health disparities-based case studies selected for student choice assignments in Year 2 and (c) percentage of health disparities-based wet lab projects selected for student choice assignments in Year 3 of the BME core curriculum.

FIGURE 5.

Interest of Biomedical Engineering undergraduates in Health Disparities-based undergraduate research and design projects. (a) Numbers of BME undergraduates who applied (black) and were selected (hashed) as undergraduate researcher mentors (UGRM) for the *Experimental Research in Engineering* course developed in partnership with the Summer STEM Institute. (b) Percentages of capstone design teams with health disparities-based challenges (hashed) against total community-based BME design projects (black) over time. (c) Percentage of BME students engaged in Zahn entrepreneurial projects and competitions. An * denotes BME winners of the Kaylie prize and a # denotes BME winners of the Zahn competition.

TABLE 1

Description of the programmatic integration of health disparities research within biomedical engineering coursework and projects.

	BME description	Type	Lecture material	Assignment(s)	Goal(s) for HD integration
YR 1	BME101: intro to biomedical engineering	Required; majors only	BME + HD lecture Guest HD lecture Podcast	Case study Editorial paper	Introduce HD-based BME projects and/or research Interest HD-based projects
YR 2	BME 220 *: biostatistics and research methods	Required; open to all Engineering	BME + HD lecture	Statistics HW Group project	Introduce awareness of HD-based statistics in BME Select HD-based project
	MHC 203: science and adv. technology in New York	Required of Honors College;	BME + HD Module Guest HD Lecture	PSA Podcast Review paper on HD of choice	Introduce HD-based issues and problems in engineering Interest in HD-based design projects and/or research
YR 3	ENGR 300 *: social, economic, cultural impacts of biomed technology	Required; open to all engineering	BME + HD Lecture	Group review paper on HD of choice	Introduce HD-based ethical problems in engineering Interest HD-based research
	BME 310: experimental methods in biomed engineering	Required; open to all engineering	BME + HD lecture HeLa cell tests HeLa book/film	Section of HD impacts in wet lab reports	Raise awareness of HD-based problems in BME Interest in experimental HD-based projects/research
	SCI 310: introduction to health disparities	Science elective	Guest BME lecture	Group paper on BME + HD topic	Introduce BME impacts of HD to non-STEM majors
	BIO 325: cancer biology	Science elective	Guest BME lecture	Group paper on BME + HD topic	Introduce underlying STEM in HD topics chosen
YR 4	BME 450: senior design I	Required; majors only	Guest HD lecture BME + HD lecture HD-based design team(s)	HD impacts in midterm report HD impacts in monthly group presentations	Produce HD-based BME design projects Engage teams in prototypes for HD-based challenges
	BME 460: senior design II	Required; majors only	Guest HD lecture HD-based design team(s)	Construct design prototype Evaluate usage	Engage teams in prototypes for HD-based challenges
YR4+	BME 591: independent study or BME project	Elective; majors only	Variable as per HD interest of student	Variable	Cultivate HD-based BME entrepreneurship projects Support HD + BME research

A variety of modules, podcasts, case studies, assignments and lectures were incorporated within required and elective courses from Year 1 through Year 4 of the undergraduate BME curriculum. An asterisk

* denotes courses in progress during time of publication.

TABLE 2

Description of select health disparities-based BME research projects completed jointly by BME undergraduate researcher mentors (UGRM) and high school students from the Summer STEM Institute.

UGRM project title	BME technical skills	Health disparities	BME applications
Differentiation of K562 cells into Erythrocyte mimics using HDAC inhibitors	Cell culture Cell imaging	Sickle cell population Cancer burden across communities	Enucleation Biochemical inhibitors
Morphological and cytotoxic effects of chemotherapy on breast cancer cells	Cell culture Cell imaging Micro-molding	Cancer incidence and community burden Clinical availability	Apoptosis analysis Toxicity study
Fluorescent imaging of bovine endothelial cells	Cell culture Image processing Micro-molding	Morbidity Diversity of clinical samples	Fluorescence Shear stress
Modeling physiological muscle wound healing <i>in vitro</i>	Cell culture Cell imaging Micro-molding	Aging Chronic wounds Pain management	Migration analysis Microfluidic systems
Quantifying glial to neuronal cell ratios of eye complexes from <i>Drosophila Melanogaster</i>	FACS sorting Brain dissections	Genetic variability Incidence of ocular disease	Retinal development Cell clustering
Formation of retinal neuroclusters on extracellular matrixes	Cell culture Micro-molding Image processing	Response to biomaterials Burden of ocular disease	Retinal Regeneration Cell adhesion

Each project had a technical focus on BME applications as well as emphasis on the associated health disparities and implications.

TABLE 3

Representative projects launched as health disparities-based BME capstone design challenges during this educational project.

Capstone Design Challenge	Known health disparities	BME team design product
EAR: engage act recover for patients of post-stroke apathy	Apathy and depression post-stroke occur disproportionately in communities with lower socio-economic status Higher burden and incidence on communities of ethnic minorities	Produced a wearable system able to emit sounds at different frequency and pitch to stimulate patient movement of affected area(s)
Virtual reality therapy for neuropathic pain relief	Treatment and management of neuropathic pain insufficient in women and racial groups Burden of pain is highest in impoverished communities	Created a visual interface for hot/cold simulation to work jointly with commercial virtual reality headsets to reduce/manage neuropathic pain
VERIpad to Manage Hypertension	Hypertension rates vary greatly across USA geographic regions Incidence is greater among women and racial minorities Higher burden documented in Impoverished communities	Created shareware and app that links iphone with disposable tests trips to validate composition of medication, patient consumption, and patterns of treatment
A portable and engaging supination device for children	Incidence of pediatric palsy-based conditions higher in communities with lower levels of education	Developed a rotational measurement system to accurately test patient strength and movement over time

Each project maintained a technical BME focus while addressing health disparities associated with each challenge.