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Ghanaian undergraduate biomedical engineering students' perceptions of their discipline and career opportunities

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ABSTRACT: Biomedical and clinical engineers are critical to low- and middle-income countries (LMICs) in order to facilitate the local design, development and production of health technologies. Undergraduate biomedical engineering programmes are growing in LMICs, but few studies have sought to understand student perceptions of their discipline. Two open-ended survey instruments were used to measure perceptions of biomedical engineering students at a large Ghanaian university. Upper and lower classmen revealed similar conceptions of what it means to be a biomedical engineer, however, they perceived limited job opportunities (almost exclusively in the sales, maintenance or procurement of hospital equipment). Furthermore, upper classmen noted the desire to pursue further education to obtain better employment, whereas lower classmen did not consider it a likely path after graduation.

Keywords: Biomedical engineering, low- and middle-income country, Ghana, perceptions, professional development

INTRODUCTION

Low- and middle-income countries (LMICs) carry a disproportionately high burden of disease. Sub-Saharan Africa accounts for 21.4% of the worldwide burden of disease, but only 0.7% of global health expenditures [1]. Much focus has been placed on increasing human capacity in the healthcare sector of LMICs. For example, low-income countries have only 0.3 physicians per 1,000 population (compared to 2.4 physicians per 1,000 population in the United States) [2]. However, increasing the human capacity in peripheral areas of the health sector such as biomedical engineering is also crucial to improving the health system in LMICs by ensuring that proper infrastructure (e.g. medical devices, laboratory equipment) is appropriate and readily available [3][4].

Medical devices are almost exclusively imported by LMICs, and donation programmes originating from high-income countries account for roughly 80% of the imports [5]. The devices, however, often fail because they are not designed for the setting [6]. Studies have suggested that a contributing factor to the lack of working medical devices is the lack of trained biomedical technicians in LMICs [3]. Mullaly found that 85% of hospitals surveyed (n = 52) reported difficulty when searching for qualified engineers to support their healthcare technologies [7].

A study in Ethiopia found that more than half of the technicians surveyed had no formal training as biomedical technicians [8]. A survey of 60 hospitals in 11 nations found that 38 of the hospitals had one or fewer biomedical technicians, and that a majority of the biomedical technicians were not formally trained as such [9].

To contribute to solving these issues, LMICs need to train biomedical equipment technicians, clinical engineers and biomedical engineers, each providing a necessary role in supporting improved healthcare delivery. Biomedical engineers apply *principles and practices of engineering science to biomedical research and health care*, clinical engineers are defined as the *professionals who support and advance patient care by applying engineering and managerial skills to healthcare technology*, and biomedical equipment technicians (BMETs) support, service and repair medical equipment including installation, calibration, inspection, preventative maintenance and repair of general biomedical and related technical equipment [10-12].

Despite their crucial role in educating biomedical engineers, biomedical engineering programmes are rare in LMICs. A study of African and North American universities found that only twelve universities offered biomedical/bioengineering

in Africa (in only six countries) compared to 229 in North America [13]. In the country of Ghana, there are less than 0.01 biomedical engineers per 10,000 population (compared to 0.49 for the United States) [14].

A survey of youth perceptions of science and technology, however, found that youths in LMICs were more interested in science (as a school subject) and were more likely to want to obtain a technology job than their counterparts in Western countries [15]. These findings indicate a disparity between the demand for education in fields such as biomedical engineering and the opportunity to pursue these careers. The relevance of biomedical engineering professional societies is an important component to furthering the biomedical profession in LMICs [3]. However, few professional societies exist in sub-Saharan Africa; for example, Biomedical Engineering Society (BMES) lists no student chapters in Africa, despite having chapters in 97 nations, and the Institute of Electrical and Electronics Engineers Engineering in Medicine and Biology Society (IEEE EMBS) lists no chapters in sub-Saharan Africa [16][17]. In Ghana, a professional society was established in 2012, but has only 15 to 20 members [18].

Previous work has described the development and curricula for biomedical engineering programmes in LMICs, yet there has been little research on students' perceptions about their discipline and future career opportunities [19]. Thus, this study investigated Ghanaian students' perceptions of biomedical engineering as a course of study and as a profession.

RESEARCH DESIGN

Study Purpose

The goal of this study was to characterise how biomedical engineering students at a Ghanaian university viewed their discipline and job opportunities and to identify the most influential factors affecting their perceptions.

The study was guided by the following research questions:

- What are biomedical engineering students' perceptions of their discipline and what influences these perceptions?
- What job opportunities do biomedical engineering students consider upon graduation and how do these opportunities compare with their perceptions of what it means to be a biomedical engineer?

Participants

Two rounds of data collection were performed. During each round, ten students from each year of study (freshmen, sophomores, juniors and seniors) in an undergraduate biomedical engineering programme volunteered for participation. Forty students completed the first survey and 40 students completed the second survey; the latter were not necessarily those who completed the first survey. All survey responses were anonymous and students were ensured that neither responses nor participation would be tied to any identifying information. All participants were Ghanaian and were representative of the total biomedical engineering student population (80/20 male/female ratio). The study was deemed exempt under the federal guidelines for research in commonly accepted educational settings (45 CFR 46.101(b)(1)).

The study was conducted within the Department of Biomedical Engineering at the University of Ghana - Legon Campus, Accra, Ghana. The academic programme began in 2004 with a cohort of eight students. The aim of the programme is *...to produce graduates who apply scientific knowledge and engineering design principles to contribute usefully to society by developing biomedical technology needed for the upgrade and maintenance of the national healthcare system*. By 2011, 34 students had graduated.

Data Collection

Two surveys were developed. The goal of the first survey, shown in Table 1, was to understand how biomedical engineering students viewed their profession, education and career opportunities through a set of five open-ended questions. Faculty (academic staff) from the Department of Biomedical Engineering distributed the survey during the first half of the academic year. The goal of the second survey, shown in Table 2, was to explore the most salient results of the first survey. The same faculty distributed the second survey four weeks after the first survey.

Table 1: First survey exploring perceptions of students towards biomedical engineering.

Number	Question
1.1	What does a biomedical engineer do?
1.2	What do you expect to do after you graduate?
1.3	What do you expect biomedical engineers to be doing in 2030?
1.4	What experiences have you had that contributed to your understanding of what biomedical engineers do?
1.5	Why did you decide to study biomedical engineering?

Table 2: Second survey exploring the most salient results from the first survey.

Number	Question
2.1	After graduation, do you intend to further your education? Why or why not?
2.2	Describe the job opportunities you will have in Ghana after graduation as a biomedical engineer?
2.3	How will your decision to pursue or not pursue further education affect your job opportunities?
2.4	Have you completed an internship in biomedical engineering? If yes, how did this internship affect your understanding of biomedical engineering careers in Ghana?
2.5	How did your courses affect your understanding of biomedical engineering careers in Ghana?

Data Analysis

The survey responses were analysed using an iterative inductive coding methodology following guidelines established for thematic analysis of open-ended data [20][21]. All responses were de-identified of the year of study and analysed as a group. Responses were read and grouped based upon similar emergent themes and by continually comparing responses to identify the similarities and differences. The process was repeated until themes ceased to change. Each respondent's year of study was then re-introduced into the data in order to determine thematic differences across academic levels.

RESULTS

In the results presented below, freshman and sophomore responses are grouped into *lower classmen* and junior and senior responses are grouped into *upper classmen*. This grouping was based upon the similarity of results found between freshman/sophomore and junior/senior students.

In the authors' exploration of what students expected to do after graduation (Question 1.2), they found distinctions between upper and lower classmen (Figure 1). While the majority of upper classmen responded that they would like to further their education or gain more experience in biomedical engineering after graduation (12 of 20), the majority of lower classmen said they would like to solve health-related issues or design new medical devices (11 of 20). For example, one upper classman stated that after graduation he would *…gain work experience in the field of bioinstrumentation.* In comparison, a lower classman stated that he would like *...to manufacture a device to diagnose diseases easily….* These two responses exemplify the differences between most upper and lower classmen.

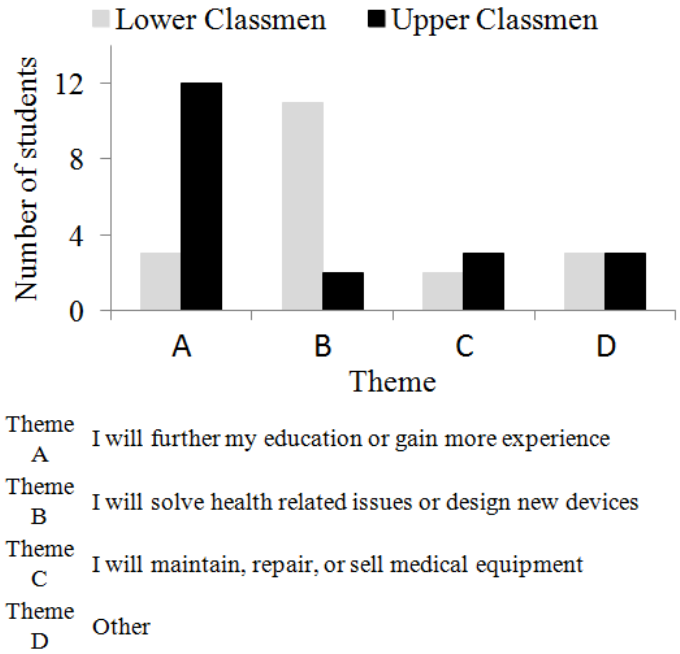

Figure 1: Thematic analysis based on responses to: What do you expect to do after you graduate?

To understand this difference further, the second survey asked students why they did or did not intend to further their education (Question 2.1) and how they thought the decision would affect their job opportunities (Question 2.3). Upper classmen believed that additional education was necessary to obtain a good job. One upper classman stated, *If I want a good job that pays well, I need to further my education.* In comparison, lower classmen mentioned needing to learn more about biomedical engineering in general or needing to specialise in a particular field (Figure 2a). The majority of students, regardless of their year of study, felt that additional education would increase their job opportunities, allow them to obtain a better job or that specialisation was needed (Figure 2b).

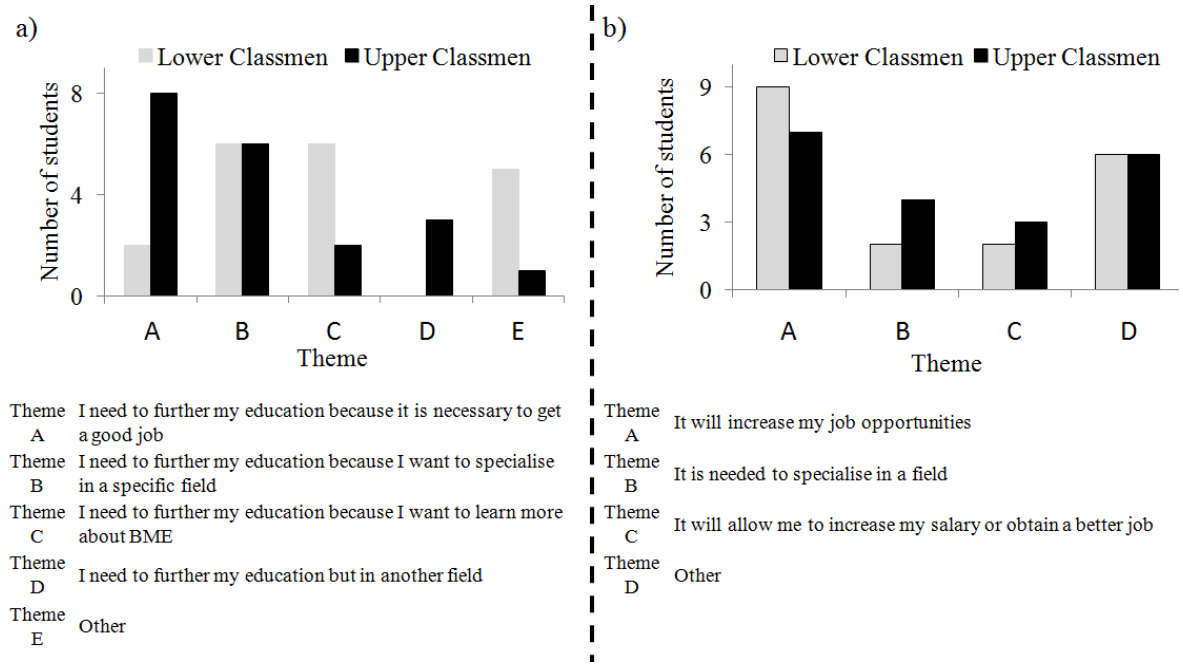

Figure 2: Thematic analysis based on responses to a) After graduation, do you intend to further your education? Why or why not? and b) How will your decision to pursue or not pursue further education affect your job opportunities?

Question 1.4 explored how students formed an understanding of biomedical engineers' job responsibilities. Upper classmen stated that internships at hospitals, research centres and/or companies were the main source of their knowledge about what biomedical engineers do in their work (Figure 3a). For example, one upper classman stated that the greatest influence was *…an internship in a hospital and I was working with the hospital engineers and that really made me want to understand what biomedical engineering really is.* Lower classmen however, relied on more diverse information sources including the Internet, examples of specific medical devices and university admissions information. One lower classman stated that he *watch[ed] Youtube videos and read articles on the Internet* in order to learn about biomedical engineering.

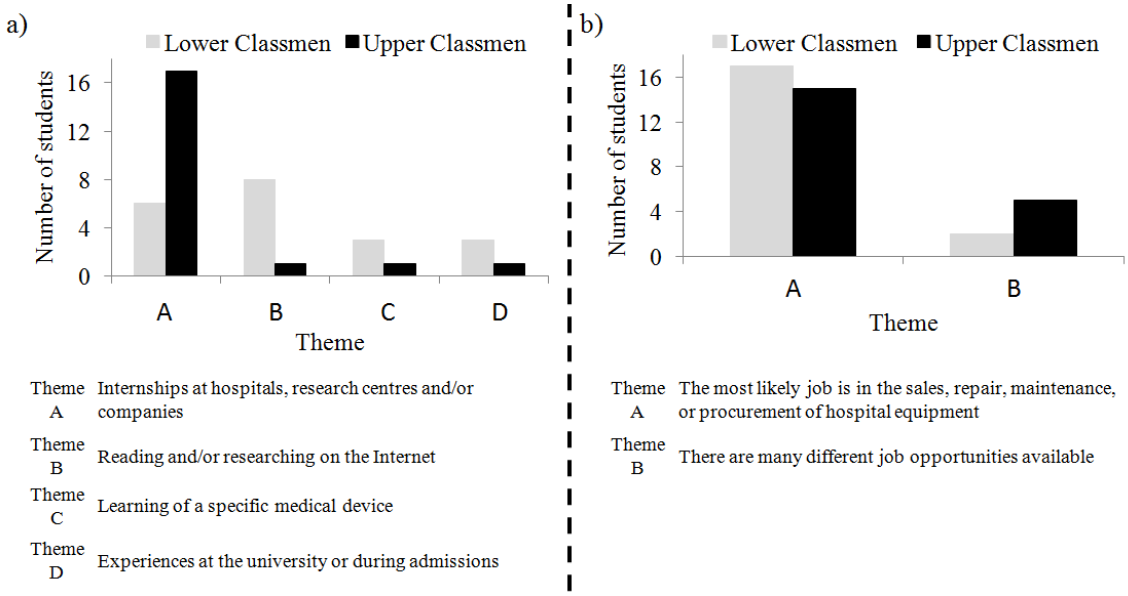

Figure 3: Thematic analysis based on responses to a) What experiences have you had that contributed to your understanding of what biomedical engineers do? and b) What do you expect to do after you graduate?

Upper and lower classmen held comparable views on the jobs that would be available upon graduating. An overwhelming majority (32 of 40) of students believed that the most likely jobs were in the sales, repair, maintenance or procurement of hospital equipment (Figure 3b). Examples of comparable views were that *…bioinstrumentation is the most practical [job available]* and that *job opportunities for biomedical engineers in Ghana are in the fields of bioinstrumentation, clinical engineering, and medical imaging at various hospitals….* These responses contrast students' perceptions of biomedical engineers' job responsibilities and the definition noted above. While students consistently cited biomedical engineers as medical device innovators, they did not see career opportunities in the design and development of novel health technologies.

DISCUSSION

Recently, a number of studies have been conducted in high-income countries to understand the attitudes of undergraduate students entering into engineering and whether the findings could be used to support student retention [22][23]. The study presented here adds to the literature by looking specifically at undergraduate students' perceptions of biomedical engineering in LMICs.

The authors observed a significant discrepancy between the students' perceptions of the work of biomedical engineers and the career options they believe are available. While 28 of 40 students stated that biomedical engineers *apply science and math to solve health care problems*, only 13 of 40 students stated that they themselves would *solve health-related issues or design new devices* after graduation. The authors also observed the discrepancy when 32 of 40 students stated that their future job opportunities would be in the *sales, repair, maintenance, or procurement of hospital equipment*. In fact, the perceived opportunities, as described by the students, most closely fit the job description of biomedical equipment technicians. This discrepancy could be due to of the lack of job opportunities in medical device development and production in Ghana, leaving students to feel that while biomedical engineers in general are engaged in solving health issues and designing solutions, they, themselves do not have the opportunity to pursue such work in their own country [24][25].

In high-income countries, the biomedical industry provides significant job opportunities for individuals with baccalaureate degrees in biomedical engineering, including opportunities to perform research in academia at the graduate level. Furthermore, students are encouraged at many undergraduate institutions to pursue entrepreneurship after graduation [26][27]. Together, these opportunities provide an array of employment opportunities that match students' perceptions of what biomedical engineers do (*apply science and math to solve health care problems*). In LMICs (such as Ghana), these employment opportunities do not exist or are much scarcer, therefore, students' perceptions of available job opportunities may simply be a reflection of what is available to them upon graduation and could provide an explanation for the survey results presented above.

Another discrepancy was the perceived need to further one's education beyond a Bachelor's degree. Only 3 of 20 lower classmen stated they would pursue post-graduate education, whereas 12 of 20 upperclassmen stated they would do so. This could be due to attitudinal changes that occur as undergraduate students progress through their education or by inherent differences between the cohorts of students. Changing perceptions would indicate that as students learn more about biomedical engineering (and participate in experiences such as internships) they realise the need for furthering their education. It is not uncommon for biomedical engineering students to be asked to repair medical equipment during their internships, so it is also possible that students realise the need for repair and maintenance skills beyond graduation in order to obtain open positions within a clinical setting [28]. Additional surveys implemented over several years should be conducted to determine whether undergraduate students' perceptions truly shift as they progress academically. These results agree with prior work in a Malaysian university, which found that students (both upper- and lower-classmen) planned to pursue post-graduate education and they felt that they were not yet prepared to become engineers upon graduating [29].

The results reveal several key findings that could support the development of biomedical engineering programmes, improve existing curricula and prepare undergraduate students for future careers in LMICs. For example, upper classmen pointed to their internships with hospitals, research centres and/or companies as a contributing factor to their perception of biomedical engineering. Identifying the aspects of these experiences that were most important and attempting to replicate them in the lower division curricula could give students an earlier understanding of biomedical engineering within their country. Further studies are needed to understand students' internship experiences in order to establish the characteristics that are most important to the development of undergraduate students' perceptions.

Additionally, the results of this study suggest that biomedical engineering students in LMICs with newly formed biomedical engineering programmes would benefit from curricular, co-curricular and/or extracurricular experiences that highlight the unique roles, responsibilities and opportunities for biomedical engineers in the healthcare sector. This could potentially be accomplished through seminars, case studies of biomedical engineers in Ghana or abroad, advising (both faculty and peer) and academic-based internships. One recent example of a novel internship opportunity paired multinational students in a clinical immersion experience to identify maternal health needs [30]. The internship exposed undergraduate biomedical engineering students from Ghana, Uganda and the United States to the front-end phases of the biodesign process involving needs and context assessments and problem definition. Upon completion of the clinical immersion experience, the undergraduate students returned to their universities and pursued design projects. Although managing expectations and communicating the intent of the students in the clinic were cited as challenges, the students were expected to be innovators as opposed to technicians. Although the small-scale pilot programme involved only four students, Ghanaian and Ugandan participants mentored their peers upon completion of the internship; thereby, creating a multiplier effect.

LIMITATIONS

The lack of information on other biomedical engineering programmes in LMICs precluded the study team from comparing the findings to other universities or from generalising the trends across institutions. The fact that demographic data from respondents were not collected, in order to maintain anonymity, prevented an analysis of

differences based on gender and age. Furthermore, the nature of the open-ended response questionnaire prevented the study team from following up with students to gain deeper information about the reasons for their perceptions. Future studies could incorporate semi-structured interviews to overcome this limitation.

CONCLUSIONS

This study sought to understand biomedical engineering students' perceptions of their discipline and career opportunities within the field. A thematic analysis elucidated several discrepancies between lower and upper classmen, implying that as the students progress through their studies, their perceptions of biomedical engineering change. An important driver of this change, as indicated by the students, was their experience with internships, which might indicate that academic perceptions of biomedical engineering differ from those found in professional settings. Across all participants, there was a mismatch between what students believed biomedical engineers do (apply engineering analysis to solving health-related issues) and the jobs that would be available after graduation (repair, maintenance and procurement of medical equipment in a hospital). This discrepancy might be expected for developing economies where medical devices are almost exclusively imported and where local design and manufacturing of medical devices has not been established.

The authors also observed upper classmen consistently mentioning the need to pursue education beyond a Bachelor's degree in order to obtain a better job, whereas lower classmen rarely mentioned the need to do so. The finding suggested that perceptions about the need for more education change as undergraduate students approach graduation. Continued improvements in biomedical education programmes in LMICs support human capacity building, which, in turn, can improve the quality and availability of healthcare in these countries.

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BIOGRAPHIES

Ibrahim Mohedas is currently a PhD candidate in mechanical engineering at the University of Michigan. He received his BS in mechanical engineering from the University of Texas at Austin in 2011. His research focuses on the design of medical devices for resource limited settings, particularly related to the use of design ethnography in developing these technologies. He works in the Laboratory for Innovation in Global Health Technology (LIGHT) and is co-advised by Shanna Daly and Kathleen Sienko.

Elsie Effah Kaufmann is a Senior Lecturer and current Head of the Department of Biomedical Engineering, University of Ghana. She holds a Bachelor of Science in Engineering (BSE), a Master of Science in Engineering (MSE) and a PhD in Bioengineering, all from the University of Pennsylvania, USA. After her graduate studies she received her postdoctoral training at Rutgers University before joining the University of Ghana in June, 2001. She was a member of the Planning Committee set up by the Academic Board of the University of Ghana to make proposals for establishing the Faculty of Engineering Sciences and was also a member of the three-person Implementation Committee set up by the Vice-Chancellor following the submission and adoption of the Planning Committee's report. She was appointed as the first Head of the Department of Biomedical Engineering in 2006. Her teaching and research focus on tissue engineering, biomaterials and application of biomedical engineering concepts to the solution of problems in the Ghanaian context. She was the recipient of the University of Ghana's Best Teacher Award for the Sciences in 2009. She is also keenly interested in Science education at all levels and has been the Host/Quiz Mistress of the Ghana National Science and Mathematics Quiz TV Programme since 2006.

Shanna Daly is an Assistant Research Scientist and Adjunct Assistant Professor in Engineering Education in the College of Engineering. She has a BE in Chemical Engineering from the University of Dayton and a PhD in Engineering Education from Purdue University. Her research focuses on design innovations through divergent and convergent thinking, as well as through deep needs and community assessments using design ethnography. Specifically, her work includes investigations of concept generation and development practices of novices through practitioners, intersections of diverse disciplines and experiences of individuals and teams that yield innovative thinking, the role of creativity in engineering and how to foster it, exploring problem spaces to identify real needs and

innovation opportunities, and developing flexibility to design both radically and incrementally. Her research is supported by the National Science Foundation, as well as the Helmsley Foundation. She teaches design and entrepreneurship courses at the undergraduate and graduate levels. Her work is often cross-disciplinary, collaborating with colleagues from engineering, education, psychology and industrial design. She received an Apprentice Faculty Grant Award from the Educational Research and Methods Division of the American Society of Engineering Education in 2008 and the American Education Research Association (AERA) Division I (Education in the Professions) Outstanding Publication of the Year Award in 2013.

Kathleen Sienko is a Miller Faculty Scholar and Associate Professor in the Departments of Mechanical and Biomedical Engineering at the University of Michigan (UM). She holds a PhD in Medical Engineering and Bioastronautics from the Harvard-MIT Division of Health Science and Technology Program, an SM in Aeronautics and Astronautics from MIT, and a BS in Materials Engineering from the University of Kentucky. She directs both the Sensory Augmentation and Rehabilitation Laboratory (SARL) and the Laboratory for Innovation in Global Health Technology (LIGHT) at the UM. She has led efforts at the University of Michigan to incorporate the constraints of global health technologies into undergraduate and graduate engineering design and is the Co-Director of the UM Humanitarian Technology Institute. Professor Sienko's educational initiatives have been recognised by the National Academy of Engineering as part of its Frontiers of Engineering Education Symposium and she has been awarded the UM Undergraduate Teaching Award, Provost's Teaching Innovation Prize, UM Distinguished Professor Award, UM College of Engineering Raymond J. and Monica E. Schultz Outreach and Diversity Award, UM Mechanical Engineering Achievement Award and UM Pi Tau Sigma Professor of the Term Award.