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Innovation Article

Creating Social Value via Undergraduate Design Thinking Course with K-12 STEM Education Outreach in Various Community Settings

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Abstract—BME HealthReach is an educational outreach program where undergraduate BME students participate in an out-of-class design thinking course to create and teach interactive STEM activities to K-12 students, where children with chronic illnesses are the primary clients. We detail research that seeks to answer the following: (1) what impact does this out-of-class design course have? (2) how does this course contribute to the entrepreneurial mindset, including promoting connection-making and creating social value/relationships? and (3) do the STEM activities achieve the educational learning objectives? BME students completed anonymous surveys pre/post-semester and descriptive statistics were used to report their viewpoints. Pediatric patients answered post-activity questions to assess the educational objectives. 98% of the BME students completed the surveys. In the pre-surveys, 49% of participants listed "teaching" as their primary goal for taking the course. In the post-surveys, 68% selected "teaching skills" as the value the course provided. Post-course reflections revealed that out-of-class opportunities positively impacted the BME students by fulfilling their desires to teach, fostering social values, and providing a creative outlet. 132 pediatric patients completed 3 STEM activities, 68% of 6th graders and above demonstrated thorough understanding of the STEM topics. 189 BME students have participated in BME HealthReach (80% participating for multiple semesters), teaching ~1500 pediatric patients and ~2500 K-12 students. The BME students enjoyed exploring connections between their course work and designing STEM activities, while building community social value/relationships. We summarize how our unique educational outreach program fosters social value within BME education and provides innovative K-12 educational programming.

Keywords—Undergraduate engineering education, Design thinking, STEM—Science, Technology, Engineering Mathematics, Educational innovations, Social value, Entrepreneurial mindset.

INTRODUCTION

As faculty members in the biomedical engineering (BME) department at Georgia Institute of Technology (Georgia Tech), we saw an opportunity for BME undergraduate students to create and implement a new paradigm of K-12 Science, Technology, Engineering, and Mathematics (STEM) educational programming in collaboration with hospital school teachers at Children's Healthcare of Atlanta, a local urban children's hospital. Georgia Tech is a large public urban research university and herein we refer to the BME undergraduate students as Undergraduate-Teachers, UTs. Children with chronic illnesses are the primary "clients" in our design thinking program, with K-12 students as our secondary clients. Accordingly, we created BME HealthReach, a 3-credit out-of-class design thinking course that allows the UTs to iteratively design and develop hands-on interactive STEM activities that emphasize that medicine is interdisciplinary and involves biology, physics, chemistry, and math. The UTs deploy and teach the activities while building meaningful, longitudinal relationships with pediatric

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patients. These relationships are beneficial for pre-medical UTs and inform their career choices within the medical field.

It is estimated that up to 20% of the school-age population have a chronic medical illness or disabling condition.[11] For reasons including disease pathophysiology, adverse effects of their therapies, and frequent school absences, children with chronic illnesses are an underserved, under-represented, and educationally disadvantaged population, resulting in academic difficulties and learning problems.[6,9,21,24] However, because children with chronic illnesses often spend significant time in the hospital, they are familiar with various aspects of science of medicine and represent a "captive audience." There is significant opportunity to supplement periods of hospitalization with educational activities, and to present a child's own disease as a model framework for learning STEM. Developing and implementing such a program, however, requires significant time and specialization that children's hospitals and pediatric clinics are unlikely to have. Universities and colleges with undergraduate biomedical engineering programs are positioned to implement such educational programs that helps build UTs' and pediatric patients' entrepreneurial mindsets through STEM learning activities, promoting connection-making, and social value/relationship creation. The entrepreneurial mindset empowers undergraduate engineering students to create personal, economic, and societal value through a lifetime of meaningful work *via* three key elements: curiosity, connections, and creating value.[10] It is through the lens of creating social value that we developed BME HealthReach, and this resulted in opportunities for UTs to make connections between their university course work and activity creation, sparked their curiosity in designing engaging educational STEM activities, and created social value/relationships through volunteering in the community. During conversations with the UTs, specific social value propositions began to emerge. Specifically, the course provided UTs a creative outlet, opportunities to interact with pediatric patients and medical staff beyond traditional observation and shadowing, the opportunity to improve the lives of children in their community through volunteering, and the perspective that a difficult exam was less challenging than a hospitalization. As such, we completed this study to capture the impact that this out-of-class design course has on the BME curriculum, and to explore how it solidifies the entrepreneurial mindset.

BME HealthReach provides extracurricular STEM education to pediatric patients, highly desirable longitudinal clinical experiences for the UTs (15–20% of our department's BME undergraduates enter medical school upon graduation), and social value for both the UT and the pediatric patient. Here we define a clinical experience for the UTs as a meaningful social interaction with a pediatric patient while teaching our STEM activities. The UTs also directly communicate with the medical team (i.e. nurses, social workers, hospital educators, and child life specialists) during their teaching experiences. In turn providing a more enriching/meaningful experience as compared to traditional observation and shadowing opportunities that pre-medical undergraduate students typically complete for medical school applications. Unlike traditional engineering courses, BME HealthReach includes a requirement for out-of-class participation: teaching our STEM activities in the community. An out-of-class activity is defined as an organized activity that a student engages in outside of formal classroom instruction and can include curricular related, co-curricular, or extracurricular activities.[19,20] Previous studies have found that in addition to their class-based cognitive growth, students develop higher-order thinking skills through a wide array of experiences outside of traditional classrooms. Specifically, in these studies, students list "tutoring other students" as positive out-of-class experiences. This supports the proposition that multiple and varied experiences shape students' cognitive and academic development.[16,17] Additionally, the 2021–2022 ABET accreditation criteria emphasizes that during their undergraduate careers, students should gain the "ability to acquire and apply new knowledge as needed, using appropriate learning strategies".[1] BME HealthReach therefore provides the UTs an opportunity to get out-of-class and into the world to teach/tutor K-12 students and allows the UTs to apply their knowledge and learning strategies in a unique way.

Specifically, BME HealthReach: (1) allows UTs to participate in the design thinking cycle that focuses on making connections between their university course work and activity creation, sparks their curiosity to design engaging educational STEM activities, and creates social value/relationships through volunteering in the community; (2) leverages the pediatric patient's own medical experience as motivation and a springboard for both activity design and learning; (3) develops hands-on interactive activities to introduce and teach STEM concepts adaptable to the pediatric patient's cognitive level; (4) provides the UTs with high quality, meaningful pediatric patient interactions and clinical experiences; (5) fosters social value and relationship building among everyone involved; and (6) provides innovative K-12 educational programming.

Herein, we present results assessing our program from the perspective of both the UTs and the pediatric patients. Regarding the UTs and our program, we explored two research questions: (1) what impact does

this out-of-class course provide the UTs? and (2) how does this out-of-class course contribute to the entrepreneurial mindset, specifically the promotion of connection-making and social value/relationship creation? Regarding pediatric patients, we investigated a third research question: do the STEM activities achieve the educational learning objectives?

PROGRAM DESCRIPTION

BME HealthReach focuses on the iterative cycle of design, development, and implementation of hands-on interactive STEM activities rooted in human physiology, where children with chronic illnesses are the primary audience and K-12 students at community STEM outreach events are the secondary audience. The UTs are enrolled in a strong traditional science and math curriculum, and as such are well-equipped to develop activities that capture the true interdisciplinary nature of medical science. The course is a special topic, depth elective course that fulfils 3 of the 12 elective credit hours required by Georgia Tech's BME curriculum, and the undergraduates are 3rd or 4th year students. Figure 1 shows our specific value proposition for the UTs, including providing opportunities to engage with K-12 students in various settings (children's hospitals, schools, community events, etc.), conducting design thinking problem solving, learning communication skills, engineering real-time iterative solutions, and creating meaningful and longitudinal relationships.

In addition to focusing on design principles, the course content includes teaching and learning topics. The UTs are taught: (1) different learning styles (visual, auditory, read-writing, and kinesthetic) among pediatric patients,[15] (2) how to incorporate various learning styles into a STEM activity, (3) Blooms taxonomy, focusing on transitioning learning from remembering to understanding to applying and analyzing,[5] (4) active learning skills,[3] (5) child development concepts related to learning theory,[4] and (6) effective communication skills. Importantly, this type of communication skill instruction is necessary for accreditation from ABET, which requires that undergraduates are taught "to communicate effectively with a range of audiences".[1] Accordingly, the UTs are provided with ample community outreach opportunities to practice their communication skills. For example, at the children's hospital, the UTs communicate with the pediatric patients, siblings, parents, and hospital staff, and adapt, in real time, to varied levels of cognitive understanding. At community STEM outreach events, the UTs interact with a wide variety of K-12 students, as well as communicate with the K-12 students' adult supervisors.

An additional benefit of BME undergraduate students serving as UTs is the relatively small age difference between the UTs and the pediatric patients. Because the BME students and school-aged children are of near-peer age, social connections resulting in relationship-building occur quickly, and the school-aged children admire the undergraduates and enjoy their time with them. This type of relationship-building is important in the cognitive development of pediatric patients and is continually emphasized by child development scholars.[4] For example, Bandura's Social Learning Theory[2] emphasizes the role of modeling and observational learning as powerful sources of development, and Vygotsky's Sociocultural Theory and Zone of Proximal Development[23] states that social interactions are necessary for children to acquire ways of thinking and behaving and that social interactions with peers can help children complete complex tasks. These cognitive development skills are valuable for both the school-aged children and for the UTs.

Lastly, over half of the UTs who participate in BME HealthReach are following a pre-medical curriculum and plan to attend medical school. Participation in BME HealthReach provides valuable clinical experience, which is an increasingly important component of medical school applications.[13] As patient privacy and in-depth credentialing requirements continue to rise, these meaningful personal relationship-building patient interactions are becoming increasingly difficult to achieve through traditional college volunteering. BME HealthReach focuses on multiple semester volunteering in which the UTs teach pediatric patients and provide a service to the hospital and community over a longitudinal timeframe.

METHODOLOGY

Each semester, through BME HealthReach, 30 to 40 UTs teach/volunteer in our local community—working with an average of 60 pediatric patients (herein referred to as patient-students (PSs)), teach bimonthly with 5th grade students (125 total) and 7th grade students (75 total) at partner elementary and middle schools, and participate in local STEM outreach events (anywhere from 100 to 1000 K-12 students). Our partner elementary and middle school are Title 1 distinguished state Department of Education certified STEM public schools. In total, BME HealthReach has served 189 UTs, more than 1500 PSs, and more than 2500 K-12 students, over 12 semesters. Recently, the program was exhibited at the American Society of Hematology annual meeting[8] where we fo-

cused on the value of the program for a specific demographic of PSs.

Each STEM activity comprises state (Department of Education) and national[7,14] standard-aligned learning objectives. New STEM activities are developed each semester as a new cohort of UTs participates in the design thinking course and contributes new educational ideas and concepts.

This program involves human subjects, and the work has been performed with approval by the appropriate ethics review committees related to the institutions in which it was performed (e.g., Institutional Review Board, IRB). The subjects gave informed consent to their inclusion in the study as required, and the work adheres to the Declaration of Helsinki. Additional details about out-of-class logistics can be found in the Supplementary Information.

As mentioned previously, this work explores two research questions focused on the experiences of the UTs and one research question focused on the educational assessment of STEM activities conducted with the pediatric PSs.

Undergraduate-Teachers

An anonymous survey study was conducted with the UTs at the beginning and end of each semester (Fall 2014 through Spring 2020) to explore our UT-related research questions: (1) what impact does an out-of-class course provide the BME students? and (2) how does an out-of-class course contribute to the entrepreneurial mindset, specifically the promotion of connection-making and social value/relationship creation? The pre-course survey study asked the following open-ended questions:

Pre Q1: What are your goals/objectives for the course?

Pre Q2: What value do you see in the course? Value is defined as what do you feel you might be getting out of this course either personally or professionally.

The UTs were asked to retain a copy of their pre-survey responses to refer to when answering the post-course survey.

The post-course survey asked:

Post Q1: In pre-course survey you were asked about your goals/objectives. Did you achieve them? Elaborate.

Post Q2: At the beginning of the course, you were asked about value, reflect on your pre-course response and now what value do you see in the course?

Post Q3: What have you learned from this class about yourself? What makes you a better student?

Upon reviewing Q1 and Q2 in the pre- and post-survey responses, we recognized emergent themes and quantified the occurrence of keywords; the top three keywords for each question were classified as the keywords for that semester. Each semester's survey responses were evaluated in the same manner and compared against each other to determine overall keywords for each question.[18] Descriptive statistics were used to report the overall keywords (summarized in Figs. 2 and 3). Direct quotes from Post Q3 are presented in full to emphasize the personal impact of the program on the UTs.

Pediatric Patient-Students

To answer our third research question (do the STEM activities achieve the educational learning objectives?), we worked directly with hospital K-12 educators in the hospital school program to create assessment questions for three "Make and Take Your Own" activities: (1) Blood Jar, (2) Bone model, and (3) Eye model (Fig. 4). The questions assessed each PS's mastery of the activities' learning objectives and are measured following our state Department of Education K-12 educational assessment scale of 0-4 (4 = Thoroughly Demonstrated, 3 = Clearly Demonstrated, 2 = Basically Demonstrated, 1 = Minimally Demonstrated, and 0 = incorrect or irrelevant).

A total of 132 pediatric patients from Children's Healthcare of Atlanta, either in inpatient or outpatient settings, were recruited for this study. Patient ages ranged from 5 to 17 years old, corresponding to kindergarten (K) to 12th grade. All PSs were enrolled in the hospital school program, where they received educational assistance for their assigned schoolwork with a Hospital School Educator (state certified school educator). Over the course of 6 semesters (11weeks/semester), the UTs led the PSs through the hands-on interactive STEM activities. Our Hospital School Educator completed the activity assessment questions with the PSs using a grading rubric (see Supplementary Information). Results from each activity assessment are shown in Fig. 4, where the numerical scores are displayed as a percentage. The percentage was calculated by taking the ratio of number of responses for each mastery category to the total number of responses (i.e. blood jar activity, High School, n = 12, 3 assessment questions, 28 Thoroughly demonstrated responses, 28/36 = 78%, 5 Clearly demonstrated responses, 5/36 = 14%, 3 incorrect responses, 3/36 = 8%).

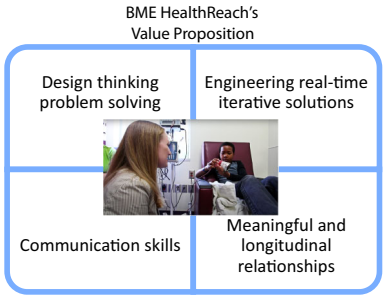

FIGURE 1. BME HealthReach's value proposition for our undergraduate participants. The program focuses on providing the BME students with opportunities to engage with school-aged K-12 students in various settings (pediatric hospitals, schools, community events, etc.), experiences with design thinking, communication skills, engineering real-time iterative solutions, and creating meaningful and longitudinal relationships. Patient image © Copyright 2014 by Georgia Institute of Technology. All rights reserved. Used/adapted with permission.

RESULTS

Undergraduate-Teachers

For the open-ended pre-survey question "What is your main objective for taking the course?" (Pre Q1), "teaching" was the most frequent keyword response (49%) (Fig. 2). This result stood out because engineering programs do not typically include classroom teaching experiences or offer opportunities for undergraduate engineers to teach other students. Here we define teaching as: sharing knowledge, presenting new information in a way that broadens a student's understanding of the world, passing understand on to someone else, giving enough knowledge to inspire further investigation, and explaining concepts to others so that they fully understand and can apply the knowledge. This last statement ties into Bloom's taxonomy[5]: learning at higher levels first requires understanding and knowledge of the foundational levels. This is a core tenet of our hands-on activities as they are designed to make the education adaptable in real-time for various cognitive levels. This adaptability further requires the UTs to improve their communication and teaching skills and be able to make real-time educational adjustments. The UTs also listed communication skills (18%), volunteering (14%), group work (10%), and career skills (9%) as their goals for the course in the open-ended Pre Q1 responses (see Fig. 2). These pre-survey responses are content topics included in the course within the lecture material, activity creation, presentations, and community outreach opportunities.

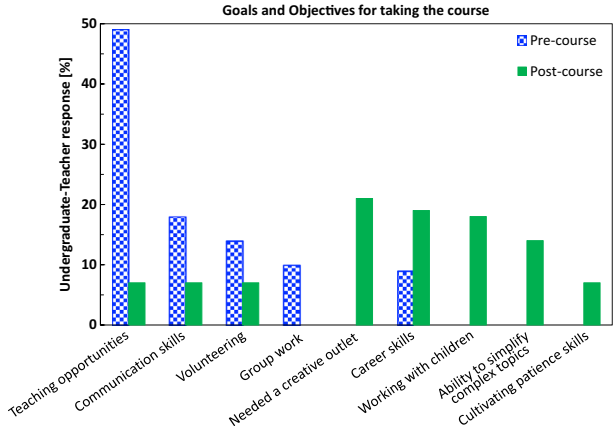

FIGURE 2. Responses from the Undergraduate-Teachers pre- and post- course survey asking about goals and objectives for taking the course. Specifically, "Pre Q1: What are your goals/objectives for the course?" 49% of the UTs said teaching opportunities was their main goal, followed by communication skills (18%), volunteering (14%), group work (10%), and career skills (9%). "Post Q1: In pre-course survey you were asked about your goals/objectives. Did you achieve them? Elaborate." The top responses included, 21% needing a creative outlet, followed by career skills (19%), working with children (18%), ability to simplify complex topics (14%), teaching opportunities (7%), communication skills (7%), volunteering opportunities (7%), and cultivating patience skills (7%). The wide variety of post-survey results show the importance of an out-of-class course provides the BME students.

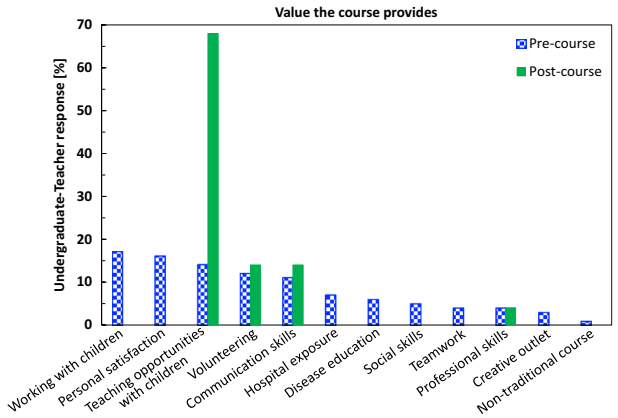

FIGURE 3. Responses from the Undergraduate-Teachers pre- and post- course survey asking about the value the course provides. Specifically, "Pre Q2: What value do you see in the course? Value is defined as what do you feel you might be getting out of this course either personally or professionally." Responses varied widely, with 17% listing working with children, personal satisfaction (16%), teaching and learning skills (14%), volunteering (12%), communication skills (11%), followed by <10% for hospital exposure, disease education, social skills, teamwork, professional skill, creative outlet, and non-traditional course. The post-survey responses had less variety. "Post Q2: At the beginning of the course, you were asked about value, reflect on your pre-course response and now what value do you see in the course?" with 68% responding that the opportunity to teach children was the most valuable aspect of the course, followed by volunteering (14%), communication skills (14%) and professional skills (4%). The overwhelming responses of "opportunity to teach" in the post-survey, showcases the importance of teaching skills to the UTs.

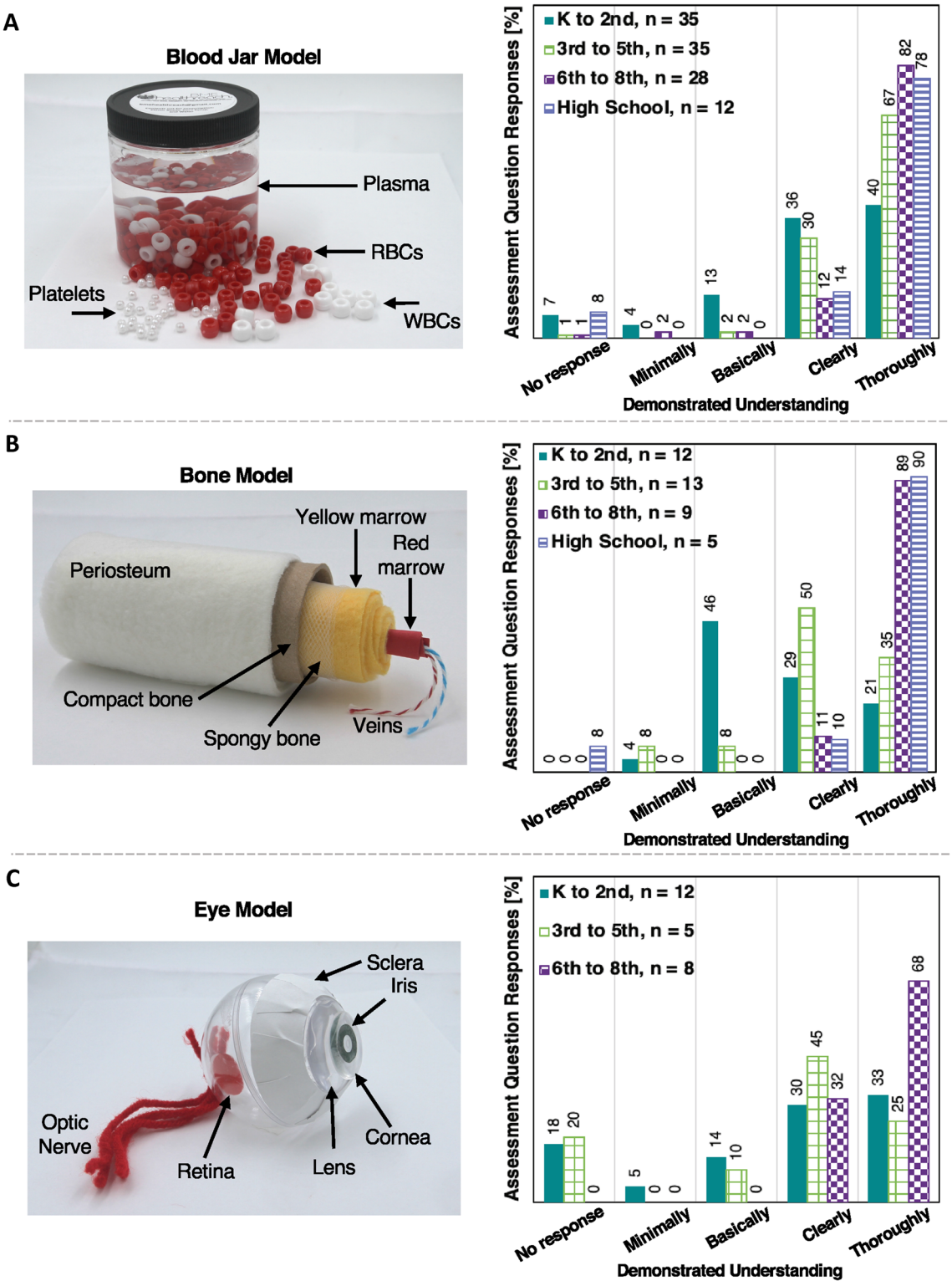

FIGURE 4. ''Make and Take'' STEM activities created by the Undergraduate-Teachers with educational assessment results from testing with pediatric Patient-Students. (a) Blood model, *n* = 110, 78% of 6th grade and above scored the highest—Thoroughly Demonstrated. Elementary struggled with scientific vocabulary, reflected in lower scores. (b) Bone model made with fabric, *n* = 39, 89% of 6th grade and above scored Thoroughly Demonstrated. (c) Eye model made with stickers, *n* = 25, 68% of 6th to 8th grade scored Thoroughly Demonstrated (there were no High School participants).

At the end of the semester, UTs were asked if they had met and/or exceeded their goals and objectives during the semester (Post Q1) and 100% of the participants responded "Yes." When UTs elaborated on their responses, the following keywords emerged: the need for a creative outlet outside of traditional engineering class setting (21%), career skills (19%), opportunities to work with children (18%), learning how to simplify complex topics (14%), teaching opportunities (7%), communication skills (7%), volunteering opportunities (7%), and cultivating patience skills (7%) (Fig. 2). These responses provide a richer view of the course's value to BME students and highlights the broader impact that the program has on their growth and development.

When asked about the perceived value of the course in the open-ended pre-survey (Pre Q2) a variety of keywords emerged: working with children (17%), personal satisfaction (16%), teaching opportunities with children (14%), volunteering (12%), communication skills (11%), hospital exposure (7%), disease education (6%), social skills (5%), teamwork (4%), professional skills (4%), creative outlet (3%), and taking a non-traditional course (1%) (see Fig. 3). This wide variety of responses emphasizes the impact an out-of-class course can have on the UTs. At the end of the semester, the UTs reflected on the value that the course provided (Post Q2) and 68% listed teaching opportunities with children, followed by volunteering (14%), communication skills (14%), and career skills (4%).

Pediatric Patient-Students

The PSs' understanding of STEM concepts was assessed to answer our third research question: do the STEM activities achieve the educational learning objectives? For the blood jar activity (Fig. 4a), the PS builds a model of blood to learn its composition, the function of each component, and the importance of hydration. At the end of the activity, the assessment questions are asked: (1) What components make up blood? (2) What task does each component of blood do? and (3) Why is it important to add water to blood? Each of the 110 responses were scored *via* the state Department of Education K-12 educational assessment scale (see Supplementary Information) and classified by grade range (K to 2nd, 3rd to5th, 6th to 8th, and High School). For the blood jar activity, we found that 82% of participants in grades 6th to 8th and 78% of participants in High School "Thoroughly Demonstrate" mastery of the learning objectives, while 67% of participants in grades 3rd to 5th and 40% of participants in grades K to 2nd "Thoroughly Demonstrate" mastery.

During the bone activity (Fig. 4b), each PS constructs a bone model to understand the function and structure of a bone, and then is asked (1) to name the 6 basic structural components of bone and (2) to describe the function of each named bone component. Mastery for this activity's 39 participants followed a similar pattern to that of the blood jar: a higher percentage of PSs in upper grade levels "Thoroughly Demonstrated" mastery (89% of grades 6th to 8th and 90% of High School) as compared to PSs in lower grade levels (35% of grades 3rd to 5th and 21% of grades K to 2nd).

During the eye activity (Fig. 4c), each PS constructs a model of the eye to learn the structure and function of the eye. The PS is then asked five assessment questions: (1) Name the 6 basic components of the eye. (2) What is the function of each named eye component? (3) Where on the eye is the iris? (4) Why does the eye dilate? (5) What is the function of the lens? Scores from 25 participants grades K to 8th (there were no High School participants) showed similar results to the other activities: 68% of grades 6th to 8th, 25% of grades 3rd to 5th, and 33% of grades K to 2nd scored "Thoroughly Demonstrated" mastery.

DISCUSSION AND CONCLUSION

In this manuscript we describe an innovation in BME education, and present objective data that begins to assess the value of our program. Specifically, we sought to understand: (1) the impact of an out-of-class course on BME students, (2) how an out-of-class course contributes to the entrepreneurial mindset of BME students, and (3) the educational impact of our hands-on STEM activities to the PSs. By examining the UTs survey responses, we can increase the impact of BME HealthReach, thereby providing the BME students with additional opportunities to engage in the community and enhance their social value.

Undergraduate-Teachers

One of the missions of our BME department is to encourage an entrepreneurial mindset by fostering curiosity, making connections by placing old ideas into new contexts, and creating value. A tenet of this entrepreneurial mindset is creating value and having an impact; within our program, this involves UTs teaching others and creating social value for the children in the UTs' community. In the course pre-survey, 49% of UTs reported "teaching" (i.e. sharing knowledge) as their main objectives for participating in the course, and in the post-survey, 68% listed "teaching" as the value the course provided. These responses highlight

the importance of incorporating learn and teaching skills into the BME HealthReach course content. As such, course lectures were bolstered to include additional content related to design thinking processes, learning styles (visual, auditory, read/write, and kinetic[15]) and how to incorporate different learning approaches into the activities, communicating a complex topic in a clear simple manner, effective use of analogies, and incorporation of Bloom's Taxonomy. The course also follows the traditional medical school pedagogy, "see one, do one, teach one"[12] where teaching is used to reinforce learning. Here the UTs solidify their own skills and knowledge as they design and teach complex STEM topics through hands-on interactive activities.

While we have presented initial findings that support the value of this program, we find that the direct quotes from the UTs' post-survey responses to Q3 provide additional invaluable insight into the value of BME HealthReach:

> "*I have learned when teaching a new topic with a patient, it makes sense to understand the underlying topics, understand the basics from the beginning. I have also found that this skill applies to my own course work.*"

> "*I also learned a lot about altering explanations and teaching methods to different audiences, which is an extremely useful life skill. At volunteer events, you could be teaching the blood jar to an 8th grader who has some background knowledge and can understand the concept on a deeper level, then the next student could be 5 years old, and you immediately must alter your explanation to someone who probably does not know anything about blood other than the fact that it is red. This is an important skill because whatever you end up doing in life, you will have to explain your work to different audiences and establish the most effective way to get your point across to a specific group of people.*"

> "*I have become more adaptable, especially in novel situations. Each time I work with a new patient I must quickly assess how much they know, where their interests lie, and what the most effective way for teaching an activity will be. I am grateful to be developing these skills now, as they are integral in medicine, and I will utilize them daily in my career.*"

> "*With each volunteer event, I surprised myself with how good I was at breaking down difficult problems and concepts into much simpler terms. Whenever a student had a question, I was able to easily make an analogy to make that connection between the material and a simple example.*"

Another main educational objective listed by the UTs in pre-Q1 was improving their communication skills, specifically improving their comfort communicating to various audiences and their ability to simplify complex topics. As was stated in the ASEE's Transforming Undergraduate Education in Engineering report,[22] "communication skills are critical for both life and a successful career… academia can introduce key concepts and can model communication skills in group projects. The skills should be integrated directly in the core engineering curriculum and not be taught in a separate course outside of engineering. Students should be presented with opportunities and encouraged to work on their communication skills, getting feedback all along the way." Our course continually integrates communication skills through the design thinking process, during class discussions, activity presentations, practice activity teaching sessions, and at outreach events. At the outreach events, the UTs teach the activity either in a 1-on-1 session or in small groups, learning in real-time how to communicate with their audience effectively and succinctly.

As mentioned previously, the three elements of the Entrepreneurial Mindset are curiosity, connections and creating value.[10] The ample out-of-class community outreach opportunities offered throughout the semester allow the UTs to teach and foster social value/relationship creation. The UTs reflected on creating their own social value through volunteering and interacting with children. Specifically, they stated the greatest assets of our program were: the opportunities to interact with children, seeing the influence their teaching has, and learning outside of the traditional engineering curriculum while achieving their main objective of teaching—sharing knowledge.

The following are direct quotes from the UT's post-survey response Q3:

> *"This class has made me appreciate being able to see the direct impact we can have on the community and our ability to help others. I have also learned important communication skills in this class. It is amazing how knowing how to explain concepts to kids can be helpful in the real world, even in my other courses. I find that it is easier for me to explain to a professor or a friend what is confusing me about certain concepts. It is also easier for me*

to explain how to do a problem to a friend and make sure they fully understand the material.''

''*I have learned that I enjoy being able to make an impact on children. What makes me a better student is that this class has motivated me to want to work harder in school because I can share my knowledge to the younger generation*.''

The responses to the self-reflection (Post Q3) provided a richer view into the positive impact the course provided to the UTs, both through social value with creating meaningful interactions with school-aged children and as they learned what makes them better engineering students. Specifically, 21% reflected on the creative outlet the course provided them, as described in the following quotes:

''*I've learned that I'm incredibly creative when it comes to designing activities. It has made me a better student by forcing me to build time into my schedule to volunteer that I wouldn't have set aside otherwise. This class allowed me to combine my passion for biomedical engineering with my passion for volunteering*.''

''*I have learned that coming up with creative ways to remember/learn things help a lot in making a topic understandable. I have started using this in other classes to break complex topics down into simple ones to make the material easy to learn and make me a better student.''*

''*I was able to learn how to think creatively again. That part of my mind has been stifled. I was able to think outside of the box and engage in projects that are different than what I typically get to work on. This makes me a better student because I can use this thinking process to be creative in my future projects and hopefully in my career. I also learned how to interact with children better and find ways to explain complex ideas to 5-year-olds.''*

These quotes articulate the deep impact and necessity a design thinking course with out-of-class community outreach provides, and how social value is created through a non-traditional engineering course. Additionally, these self-reflection responses highlight that BME HealthReach also inspire the other 2 basic tenets of the entrepreneurial mindset—curiosity and connections. Through creating their own STEM activities, the UTs can be curious and explore interesting ways to teach STEM through hands-on activities. The course aligns with ''connections,'' bringing together the student's knowledge and interest in engineering with volunteering and sharing their knowledge through teaching. Therefore, the course directly aligns with the mission to inspire the entrepreneurial mindset.

Pediatric Patient-Students

Verbal feedback from patients and their families has been overwhelmingly positive: they state that the STEM activities are ''fun'' and ''engaging,'' and many PSs, parents, and medical providers have requested that the UTs return the following day. However, quantitatively evaluating mastery of learning objectives is critical to BME HealthReach's long-term success as an educational outreach program at the hospital. Our educational assessment sought to determine the percentage of PSs that achieved the highest level of understanding—the score of ''Thoroughly Demonstrated''—for our STEM activities.

Our results show that at minimum 68% of PSs in 6th grade and above ''Thoroughly Demonstrated'' understanding of the STEM topics taught in all activities, while K to 2nd and 3rd to 5th grade PSs did not achieve that level of understanding. However, lower scores for those patients were due primarily to difficulties remembering new scientific vocabulary. For example, it may have been the first time they heard the words ''platelet'' or ''plasma.'' Future work will modify both the learning objectives and assessment questions, to be grade appropriate.

One limitation of this learning objective evaluation is that the assessment questions are asked shortly after activity completion, therefore there is no long-term knowledge retention tracking. To that end, because our population comprises of children with chronic illnesses who frequent the hospital, we will assess long-term knowledge retention of the activities in future school years and add in new STEM activities created by the UTs.

Overall, BME HealthReach represents an innovative and novel approach for STEM education with direct benefits to BME students and K-12 students. Specifically, BME HealthReach: (1) allows UTs to participate in the design thinking cycle that focuses on making connections between their university course work and activity creation, sparks their curiosity to design engaging educational STEM activities, and creates social value/relationships through volunteering in the community; (2) leverages the pediatric patient's own medical experience as motivation and a springboard for both activity design and learning; (3) develops hands-on interactive activities to introduce and teach STEM concepts adaptable to the pediatric pa-

tient's cognitive level; (4) provides the UTs with high quality, meaningful pediatric patient interactions and clinical experiences; (5) fosters social value and relationship building among everyone involved; (6) provides innovative K-12 educational programming; and (7) provides out-of-class experiences to the engineering curriculum. We envision BME HealthReach as a model framework for other BME undergraduate programs, providing innovative K-12 STEM education to pediatric hospitals nationwide.

SUPPLEMENTARY INFORMATION

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AUTHOR CONTRIBUTIONS

Dr. ETH, Ms. SIF, and Dr. WAL conceptualized and designed the work, as well as co wrote, reviewed, and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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DATA AVAILABILITY

Data is available.

CONFLICT OF INTEREST

All authors have indicated they have no potential conflicts of interest to disclose.

ETHICAL APPROVAL

Human Participants—Emory University IRB—IRB00114382, Georgia Institute of Technology IRB—H20186.

CONSENT TO PARTICIPATE

Human Participants—Emory University IRB—IRB00114382, Georgia Institute of Technology IRB—H20186.

CONSENT FOR PUBLICATION

Human Participants—Emory University IRB—IRB00114382, Georgia Institute of Technology IRB—H20186.

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