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Building a Partnership Between a University and Local High School to Foster and Grow Interest in Biomedical Sciences and Engineering

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To help foster interest in science, technology, engineering, and math (STEM), it is important to develop opportunities that excite and teach young minds about STEM-related fields. Over the past several years, our university-based research group has sought to help grow excitement around the biomechanics and biomedical engineering fields. The purposes of this technical brief are to (1) discuss the development of a partnership built between a St. Louis area high school and biomechanics research lab and (2) provide practical guidance for other researchers looking to implement a long-term outreach program. The partnership uses three different outreach opportunities. The first opportunity consisted of 12th-grade students visiting university research labs for an up-close perspective of ongoing biomedical research. The second opportunity was a biomedical research showcase where research-active graduate students traveled to the high school to perform demonstrations. The third opportunity consisted of a collaborative capstone project where a high school student was able to carry out research directly in a university lab. To date, we have expanded our reach from 19 students to interacting with over 100 students, which has yielded increased interest in STEM related research. Our postprogram survey showed that outreach programs such as the one described herein can increase interest in STEM within all ages of high school students. Building partnerships between high schools and university researchers increases the interest in STEM amongst high school students, and gives graduate students an outlet to present work to an eager-to-learn audience. [DOI: 10.1115/1.4064664]

Introduction

Today's society is heavily dependent on technology, in both systemic and personal ways. As younger generations age in a society driven by technological advancements, automations seem to evolve quicker than ever to meet the increasing demands of societal systems and structures. To keep up with these constant changes, there is a strong need for young minds to engage in STEM fields [1,2]. With the help of increased numbers of programs and funding opportunities over the past several decades, informal STEM education opportunities are being developed. These experiences are crucial in sparking interest in STEM and helping to sustain interest through students' educational timelines [3,4].

Not only does outreach work to introduce STEM to a larger group of students, but university-based outreach programs also give undergraduate and graduate students unique opportunities to improve their skills as science communicators. A recent survey of graduate students showed that 93% of respondents categorized "doing a science demo for an outreach program" as an activity that falls within science communication [5], suggesting that graduate students believe outreach programs are an effective method for communicating science more broadly. In addition, outreach programs also allow graduate students to act as civic scientists. Effective civic scientists engage in active dialogue with their local

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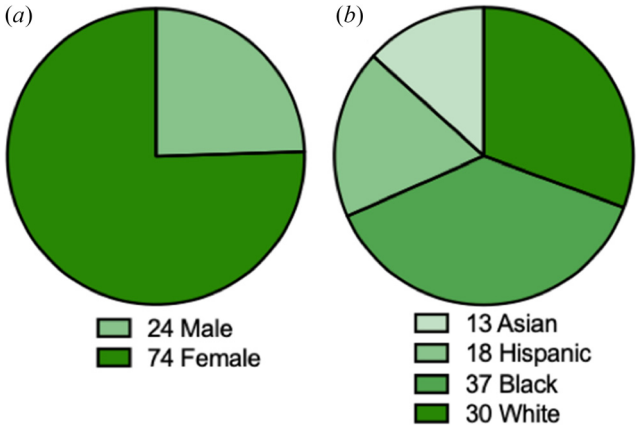

Fig. 1 Potential pool of student participants in our partnership programs: (*a*) gender distribution of all BSP students (2022–2023 academic year) and (*b*) distribution of ethnic background for all BSP students (2022–2023 academic year)

communities [6], which creates a strong relationship between scientists and the general public. Enhanced communication can also encourage younger generations to enter STEM fields and increase support for STEM topics among older generations.

Our institution, Washington University in St. Louis (i.e., WashU), has an engaging population of students, many of whom have previously demonstrated an interest in outreach by volunteering for other outreach programs with middle school or high school aged students such as BrightPath STEAM, Young Scientists Program, and Letters to a Pre-Scientist. Here, we (a university research lab and secondary school educator described below) describe our process of creating several opportunities for high school students to engage in STEM, thus creating a long-term outreach program between biomedical and mechanical engineering students at WashU and a local St. Louis area high school. The aim of this program was to introduce new engineering ideas to a group of high school students while offering graduate students the opportunity to grow as civic scientists and improve their science communication skills. With the introduction of these topics to a growing group of students, the hope is to increase the number of young students who continue their education and follow a path into STEM related fields, thus creating a positive loop of individuals who learn about STEM, enter into a STEM related field, and grow themselves as civic scientists through future outreach opportunities.

Partnering High School. Pattonville High School (PHS) is part of the fully accredited and nationally recognized Pattonville School District which, according to the National Center for Education Statistics (NCES), has prekindergarten through twelfth grade students and is centrally located in St. Louis County, Missouri. NCES reports that PHS is composed of grades nine through twelve with 1802 total students for the 2021–2022 school year (591 freshman, 436 sophomores, 393 juniors, 382 seniors).

Project Lead the Way Biomedical Sciences Program. In the 2013–2014 school year, PHS initiated their involvement in the national Project Lead The Way Biomedical Sciences Program (BSP), a rigorous 4-year, four-course sequence in which students learn about medicine, physiology, genetics, microbiology, public health, and forensic science. During the 2022–2023 school year, 6.6% of the student population of PHS was enrolled in the BSP, which included 24 male and 74 female students across all four grade levels (Fig. 1(*a*)). These students represented a diverse snapshot of the school with 37 Black, 30 White, 18 Hispanic, and 13 Asian student participants (Fig. 1(*b*)). Because BSP courses focus predominantly on health sciences and biological sciences, the partnership with our lab represents a valuable opportunity to introduce BSP students to biorelated fields within engineering such as biomechanics and biomedical engineering.

Main Partnering Washington University Laboratory. The Musculoskeletal Soft Tissue Laboratory (mSTL), directed by Dr. Spencer Lake, is in the Department of Mechanical Engineering & Materials Science within the McKelvey School of Engineering at Washington University in St. Louis. The lab's research investigates the biomechanics of orthopedic soft tissues such as tendons and ligaments to enhance fundamental understanding of healthy tissue properties and elucidate changes that occur in injured or diseased tissues. Members of the mSTL regularly participate in several annual outreach events to provide interactive educational opportunities for middle and high school students from the St. Louis area. Taken together, our partnership with PHS and regular participation in other campus-based outreach events allows members of our lab specifically to connect with a large number of K-12 students across a wide range of ages.

Establishing a Connection. While writing an educational aim for a National Science Foundation grant proposal (NSF CMMI 2037125), the members of the mSTL discussed potential ideas to engage with the St. Louis community. The BSP at PHS was brought into focus as a potential group who would benefit from connecting with labs at WashU. Establishing the first-time connection is key to building successful opportunities for outreach. We sought an opportunity to establish a connection with a known community prior to reaching out more broadly to unknown potential partners. The first author (R.M.C.) is an alumnus of PHS and currently resides within Pattonville School District. With the hope of increasing interest in biological engineering in the local community, a logical first step was to return to where his initial interest in STEM was born. An email from the principal investigator (PI) of the mSTL to the lead educator for the BSP established the initial connection. The initial group that was created to help develop and implement this program included one PI, one lab technician, several graduate students, one BSP educator at PHS, and one PHS administrator.

Overall Goals. With the convenient location of WashU's campus, the funding opportunities available to research labs, and the mission of WashU to enhance not only the lives and livelihoods of students, patients, and employees but also the people of the greater St. Louis community and beyond, we are well suited to promote and teach STEM concepts to area K-12 schools. After several brainstorming sessions and discussions, our initial idea was to thoughtfully select a single local high school (PHS) with whom we could build a strong partnership for outreach/education that could grow and expand over time. We subdivided this overall goal into three specific opportunities, which are designed to be adaptable as the relationship develops and students' interests change.

Implementation

This project has been reviewed by the Washington University Research Protection Office, which determined that it does not involve activities that are subject to Institutional Review Board oversight. Additionally, all individuals (or guardians of individuals) shown in photographs have given permission.

Opportunity 1: Senior Student Visit to Campus (4–6 Weeks After Beginning of School Year). Goal: Invite 12th-grade BSP students for a half-day field trip to WashU's McKelvey School of Engineering to visit several engineering labs and tour engineering facilities.

University-associated Personnel: (3 PIs, 6–8 Graduate Students, 1 Lab Technician).

Our initial focus was on engaging with senior students who were in their beginning stages of planning for their capstone research projects. Advantages of this approach included a relatively small

class size (which simplified logistical aspects for a campus visit) and more educationally advanced and mature students. To plan this event, an initial list of all biomedical and mechanical engineering labs was compiled and sent to the senior BSP students at PHS. From this master list, students were given time in class to investigate each lab online, allowing students to get a general idea of the specific type of research conducted by each lab as well as a general perspective of the breadth of biomedical research conducted at WashU. After evaluating each potential research lab, students ranked their relative interest in visiting each lab; results were compiled and used to solicit participation from the labs that generated the most interest. The visit to WashU's main academic campus was planned to last half-a-day and give the students time to experience multiple lab settings as well as participate in a tour of the engineering buildings and facilities available at WashU (Table 1). After a brief welcome and introduction, students were given a previsit survey (see Table 2) and participated in a kickoff discussion. Students were then split into smaller groups prior to visiting each of the three participating labs on a rotating schedule. Each lab was encouraged to create a simple, safe demonstration to show the students and help explain the main research focus. This structure allowed students to see a variety of research topics and lab settings while visiting campus.

First Year Visit (2021). During the first year of the program (2021), 19 senior students (Figs. 2(*a*) and 2(*b*)) participated in the on-campus program. In the first lab, students learned about several experimental techniques that are commonly used in a biomechanics laboratory. Demonstrations included (1) how an animal model is used to study post-traumatic joint contracture, (2) how simple custom-built devices (e.g., using Arduino coding and circuit building (Fig. 3(*a*)) are used in engineering labs to collect experimental data, (3) dissection of rat tail tendons followed by tensile mechanical testing (Fig. 3(*c*)) of the freshly harvested tendons, and (4) the use of polarized light imaging to detect structural features not visible to the human eye, specifically by giving students the opportunity to create "art" that was visible only through this imaging technique (Fig. 3(*b*)). The second lab that students visited explores the mechanobiology of multiple joints within the musculoskeletal system. During this lab tour, students learned about new medical treatments targeting the intervertebral disks of the spine and saw demonstrations of research involving diarthrodial joints such as the knee joint. The third lab investigates the design and computing principles of biological sensory systems, with particular emphasis on the sense of smell (i.e., olfactory system). In this lab, students learned how model organisms such as locusts can be used to study olfactory circuits to gain a deeper understanding of how they work.

Table 1 Itinerary for the opportunity1 visit to the Washington University campus

Campus visit itinerary	
8:00 am	Arrival at Washington University Danforth Campus
8:10–8.35 am	Kickoff: introductions, brief overview of biomedical research
8:40–9.25 am	Lab Visit #1
9:30–10.15 am	McKelvey Engineering Buildings Tour
10:20–11.05 am	Lab Visit #2
11:10–11.55 am	Lab Visit #3
12:00 pm	Reconvene and departure from Washington University

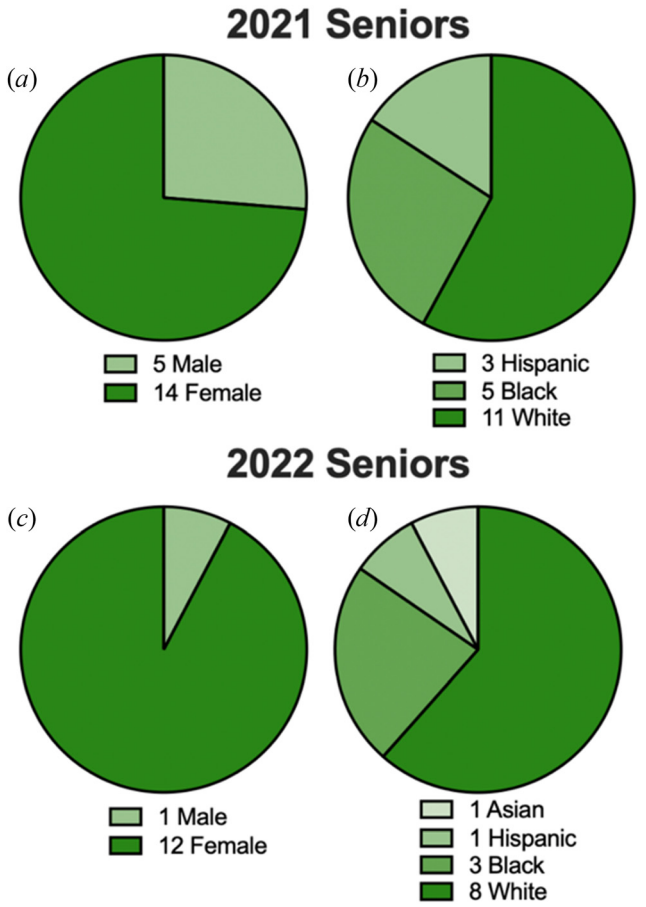

Fig. 2 The senior students of the biomedical sciences program at Pattonville high school who participated in opportunity 1. Class of 2021 distributions of (*a*) gender and (*b*) race. Class of 2022 distributions of (*c*) gender and (*d*) race.

Table 2 List of survey questions the high school students completed previsit (top portion) and postvisit (bottom portion) for opportunity 1

Question #	Previsit survey
1	Before this visit begins, how much do you know about the Biomechanics/Biomedical engineering field?
2	When you hear the term Biomechanics or Biomedical Engineering, what comes to mind?
3	What's one thing you are hoping to see or learn today?
Question #	**Postvisit survey**
1	How satisfied are you with the amount of activities you saw/did today?
2	After this visit today, how much do you know about the Biomechanics/Biomedical Engineering field?
3	When you hear the term Biomechanics or Biomedical Engineering, what comes to mind?
4	Did this visit today increase your interest In the field of Biomedical Engineering?
5	Which lab demonstrations did you find most interesting?
6	Would you be interested in connecting with a graduate student for mentorship during your senior capstone? (i.e. Someone to ask questions to or work with to collect data)
7	Please in the space below leave any comments about this overall visit. Please feel free to mention likes and dislikes.

Fig. 3 BSP students learned about a variety of research techniques during the half day visit (opportunity 1): (*a*) Undergraduate student showing a demonstration on Arduino coding and circuit building, (*b*) graduate student explaining and showing quantitative polarized light imaging technique, (*c*) two graduate students setting up a mechanical test demonstration, and (*d*) students playing a video game using only motion from their legs

Second Year Visit (2022). In the second year of the program (2022), 13 senior students (Figs. 2(*c*) and 2(*d*)) participated in the on campus visit and visited a few different labs from the previous year due to varying interests. Once again, the students were sent a list of potential labs and voted on which topics were of highest interest. As the main hosts of the event, our lab's participation and demonstrations stayed the same as the first year. The second host lab seeks to improve movement after spinal cord injuries through neurorehabilitation. During this visit, students learned about the use of wearable sensors to track three-dimensional movements and were able to test such sensors themselves while playing a video game using only the movement of their legs to control the game (Fig. 3(*d*)). The third host lab aims to understand the mechanisms underlying the spread of infectious disease, specifically by better understanding infectious viruses. During this lab visit, students learned how viruses infect their host and then used a microscope to visualize several aspects of infectious disease models through imaging and analysis.

Engineering Campus Tour. During the half-day visit to campus, high school students were given a guided tour of the engineering buildings which allowed them to see different types of lab spaces (e.g., wet labs, computational labs, teaching labs). Students were also shown several spaces that are important for the undergraduate engineering experience (e.g., machine shop, makerspace, and student study spaces). The tours were led by a staff member from engineering undergraduate student services and assisted by current engineering undergraduate students. The tours provided an opportunity for the visiting high school students to observe various aspects of the engineering education and ask current students about their interests and experiences.

Table 3 List of questions the high school students completed following the biomedical research showcase (opportunity 2)

Question #	Post-showcase survey
1	What is your current grade level?
2	What made you interested in joining the Biomedical Sciences Program at PHS?
3	What field within the biomedical sciences are you most interested in?
4	Before the showcase began, how much did you know about engineering approaches for studying biomedical topics?
5	What is one thing before the showcase you were hoping to experience, see, or learn about?
6	How satisfied were you with the amount of activities/demonstrations you saw today?
7	After the showcase, how much more do you know about the engineering studies of biomedical topics?
8	From all the showcase tables, did you learn about any new-to-you fields of biological studies? if yes, what was the new field?
9	When you hear the term "biomedical engineering" what comes to mind?
10	Did the showcase increase your interest in biomedical engineering?
11	From what you saw today, are you interested pursuing a different avenue of biological studies?
12	What's the coolest thing you saw or learned from the showcase?
13	We want to make this the best that we can! Please give us any feedback you have to make this event better for future years.

Opportunity 2: Biomedical Research Showcase at High School (4–6 Weeks Into Second Semester). Goal: Present a showcase of biomedical engineering research topics to all BSP students (9th–12th grade) at PHS, increasing the total number of student interactions and allowing more graduate students to strengthen their science communication skills.

University-associated Personnel: (2 PIs, 10–12 Graduate Students, 1 Lab Technician)

For Opportunity 2, the goal was to reach a larger group of BSP students than just the seniors who participated in Opportunity 1. In order to reach a larger group of students across all years of the BSP, we developed a biomedical research showcase that could be brought directly to the high school. The overall idea of Opportunity 2 was to invite a group of research-active graduate students from WashU across a range of research areas to visit the high school and give lightning (10-min) demonstrations related to their research. The intended outcomes of the showcase were twofold: not only would the high school students learn about biomedical engineering topics and interact with students who are active in research, but the graduate students would also have the opportunity to engage with a new audience to present their work. At the showcase, high school students were split into two groups: one group composed of sophomores, juniors, and seniors, and one group limited to freshmen only due to the larger number of first-year students participating in the BSP compared to other grade levels. Students were subdivided into groups of 4–6 and sent to an initial presentation followed by rotations every 10 min (Fig. 4), giving them time to explore many topic areas within biomedical engineering.

For the first year (2023), we were able to bring ten graduate students from nine different labs to present on their different research areas. Each graduate student was asked to create an interactive presentation or demonstration that would be exciting and engage well with the high school students. The ten participating graduate students brought a wide range of different interactive materials that included poster presentations, slide presentations, tangible visuals aids, and hands-on demonstrations. Research topics presented by the volunteer graduate students included women's health, soft tissue biomechanics, acoustofluidics/microfluidics, optical neuroimaging, virology, and biomedical imaging. Following the showcase, all participating students were asked to complete an online survey to provide feedback on the event (Table 3).

Opportunity 3: Collaborative Senior Capstone Project (Entire Second Semester). Goal: Host interested students back at WashU's campus to conduct basic research over a multiweek span under the direct supervision of a graduate student to comprise a senior capstone project.

University-associated Personnel: (1 PIs, 1–2 Graduate Students, 1 Lab Technician)

The final opportunity in the partnership program between WashU and PHS was designed to allow a high school student to partner with a lab to conduct data collection for their senior capstone project. As a final requirement of the BSP program, senior students design and execute a final research project which encompasses all they have learned about biological sciences and research during their 4 years in the program. To date, one student has successfully partnered with our lab to conduct a research project using polarized light to image collagen fiber dynamics in tendon during mechanical loading. After visiting the campus during Opportunity 1 and participating in multiple demonstrations, the student selected the topic they found most interesting for their research project. The student then partnered with a graduate student mentor in our lab, conducted all safety training needed to become a student researcher, and came to lab on a weekly basis for the duration of the spring semester to plan experiments, conduct testing, and analyze data. Once all data were collected and analyzed, the student created a final presentation for their senior year and presented their capstone project for a final grade.

Overall Implementation and Logistics

Throughout the year, we (Pattonville educators and mSTL members) are in constant communication via email and video meetings to coordinate dates for events and plan each opportunity. For each opportunity, recruitment of other labs and PIs is done by members of the mSTL via email and Google Forms, labs are sent a brief description of each event and participation is based solely on

Fig. 4 Graduate students presented their research to 9–12 grade BSP students during the biomedical research showcase at Pattonville high school (opportunity 2)

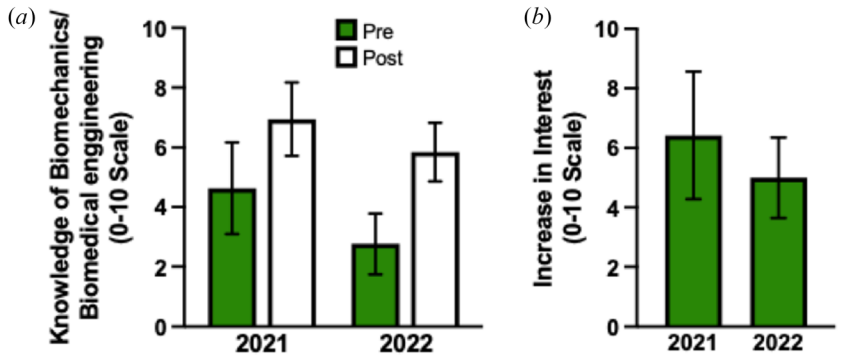

Fig. 5 (*a*) Average score (scale: 1–10) of knowledge prior to the visit and after the visits. (*b*) Average score (scale of 1–10) of whether there was an increase in interest in biomechanics/biomedical engineering. 0 indicates no knowledge or no increase in interest, while 10 indicates total knowledge or maximum increase in interest (data shown as mean ± standard deviation).

volunteering. Once a list of participating labs and PHS students is finalized, programs are registered through WashU's Youth Protection department to verify compliance with all regulations in place for working with minors. Although the initial idea of this partnership was developed as part of an NSF proposal, all continued events are supported from university and high school funds. Specifically, all materials used for hands-on demonstrations are donated by participating labs, PIs and students volunteer their time, and the high school supports costs related to the field trip for Opportunity 1 (e.g., transportation to and from campus).

Evaluation

In order to evaluate the success of our new partnership, students were given previsit and postvisit surveys for Opportunity 1 and a postactivity survey for Opportunity 2. Success for Opportunity 1 was evaluated based on an increase in overall perceived knowledge of biomechanics/biomedical engineering, an increase in interest of the field, and whether senior high school students were interested in mentorship with a graduate student. Similarly, Opportunity 2 success was based on an increase in perceived knowledge and interest of biomechanics/biomedical engineering and whether we were able to increase the number of students with whom we interacted. Of note, for Opportunity 2, both pre- and postactivity perceived knowledge and interest were assessed from a postvisit survey since we were unable to obtain survey data prior to the research showcase. Opportunity 3 has no measurable levels of success from surveys; however, success can be measured based on completion of the overall goals of the student who completed data collection at WashU.

Opportunity 1 Evaluation. In addition to rating the overall success of the visit to WashU's campus (Table 2), the pre- and postvisit survey questions were also used to determine what the students were hoping to see or learn during the visit, which labs they found the most interesting, whether the number of activities was appropriate, and any other thoughts they wished to share. Using a scale from 1 to 10, there was an increase in perceived knowledge of biomechanics/biomedical engineering for students in both years 1 and 2 after participating in the visit to campus (Fig. 5(*a*)). There was also a noticeable increase in overall interest of biomechanics/biomedical engineering (Fig. 5(*b*)). Interestingly, students also expressed a great deal of interest in receiving mentorship from graduate students while completing their capstone projects. Sixteen senior students in 2021 (84%) and nine senior students in 2022 (82%) indicated interest in being paired with a graduate student to give them the opportunity to ask questions, conduct experiments, and collect data (Fig. 6).

Opportunity 1 High School Student Feedback. Responses to an optional, open-ended request for feedback on the program resulted in 84% positive comments, 3% negative comments, and 13% of students who provided no response. Listed below are a representative sample of the positive direct quotes received from the Opportunity 1 postvisit surveys. The negative quote is highlighted in the discussion:

- "I really liked the visit. It was very informational and I liked that I got to explore different careers."
- "I really liked how informative this visit was. I feel I have a totally different view of this field."
- "I would like to thank all of the faculty, teachers, and students for doing this for us. It was a wonderful experience. Thank You!!!"
- "People were very nice and approachable. Everyone wanted to answer questions."
- "The experience was overall amazing, I loved getting to learn about the different labs/research WashU is doing."
- "I think that the labs were described well given our previous knowledge of anatomy and other concepts. They also seemed happy to have us there."
- "I loved all the labs and be able to do some hands-on learning."
- "Thought it was so cool, I am so much more interested in bioengineering now."

Opportunity 2 Evaluation. In addition to the questions intended to evaluate the perceived knowledge of biomechanics and biomedical engineering, the postshowcase survey also contained qualitative, opinion-based questions that allowed high school students to share their thoughts on the strengths and weaknesses of the program. Responses to these questions give beneficial insight

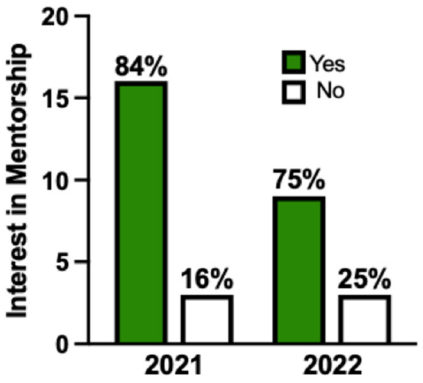

Fig. 6 Count of the number of students who would be interested in connecting with a graduate student for mentorship during their senior capstone project. Percentages shown are percent of total group for each given year.

into whether the event was a success and provide feedback regarding what can be changed to improve the event in future iterations.

One of the main goals for Opportunity 2 was to increase the number of students with whom we were able to connect, which we were successful in achieving. Less than 20 students attended the campus visits each year in Opportunity 1, while nearly 100 students participated in the biomedical research showcase in Opportunity 2. Another goal was to provide a broader view of topics within biomedical research, which we were also able to accomplish: nine labs were represented in the research showcase compared to three labs each year during the campus visit. Out of the 98 students enrolled in the BSP at the time of the showcase, 52 completed the postevent survey (Fig. 7(*a*) breaks down respondents by class). Attendees displayed an overall increase in perceived knowledge of biomedical engineering (Fig. 7(*b*)). When asked whether their interest in the field had increased, 32 students (62%) marked "yes," 16 students (31%) marked "maybe" and 4 students (8%) marked "no" (Fig. 7(*c*)). Qualitative, open-ended questions that allowed students to express their opinions revealed that students enjoyed the variety of topics, and many wished they could have had more time to interact with each graduate student presenter.

Opportunity 2 High School Student Feedback. Responses to an optional, open-ended request for feedback on the program resulted in 38% positive comments, 31% negative comments, and 31% of students who left no comment. Listed below are several direct quotes received from the Opportunity 2 postevent surveys, both positive and negative:

- "I loved how positive and nice all the students were. They all seem passionate about what they are doing."
- "I really enjoyed the stations that had hands on or up close examples with their presentation."
- "I loved all the tables and thought they were all cool. Future classes would love this."
- "I wish there was more time but overall it was perfect and really educating."
- "I learned about Biomedical studies and the connection of engineering within the medical field."
- "Some topics are to complex."
- "I wish it was longer so we had more time to go to every station."
- "Some off the stations weren't very interactive, and I realized that I retained more information from the stations that were interactive."

In addition to the surveys filled out by the high school students, several of the graduate students offered feedback after the showcase event. An overall reoccurring theme in the comments from graduate students was thankfulness for the opportunity to present their research to the high school students and an overall feeling of a successful event. One of the graduate student volunteers said, "Students of all ages were engaged and asking unique and insightful questions, and I think they really connected with the props that were brought in." Thus, evaluation of our first iteration of the biomedical research showcase suggests a successful event with positive outcomes for both high school BSP students and volunteer graduate student presenters.

Opportunity 3 Evaluation. Although we have no survey data from the one student who completed data collection for their senior capstone project in the mSTL, success of this opportunity can be evaluated based on completion of their goals. The student successfully built a relationship with a graduate student in a biomechanics lab where they carefully planned out their project, ran a series of well-designed experiments, and then collected and analyzed data. From these data, the student was able to compose a final capstone report and create a formal presentation, which completed the final task of the BSP requirements at PHS.

Discussion

Learning and increased interest in STEM can result from a well-balanced outreach partnership or collaboration. Our goal was to build a mutually beneficial partnership with a local high school where our students could work on becoming better science communicators while also providing outreach/educational experiences to introduce and teach biomedical engineering concepts to a younger group of students. We have successfully created and implemented three opportunities for our university-high school partnership that have impacted students through several different types of activities and interactions.

To help increase interest in biomechanics/biomedical engineering within the BSP, we plan to continue inviting seniors to visit campus yearly as described in Opportunity 1. We also plan to conduct the biomedical research showcase (Opportunity 2) on an annual basis to continue reaching a large cohort of students and give graduate students the opportunity to share their work. For Opportunity 3 we would like to invite more students to conduct their data collection (for senior capstone projects) on campus and increase the number of labs willing to host these seniors. In addition to the three opportunities that have already been implemented, other

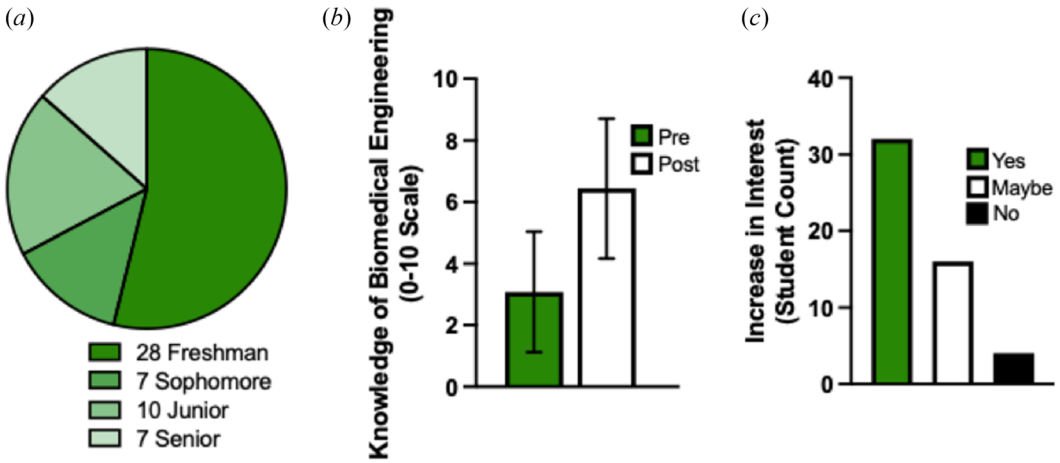

Fig. 7 Results from the biomedical research showcase (Opportunity 2): (*a*) breakdown of students who completed the survey, (*b*) overall knowledge of biomedical engineering increase from before the showcase to after (0 indicates no knowledge, 10 indicates total knowledge with data shown as mean ± standard deviation), and (*c*) a majority of students had increased interest in biomechanics/biomedical engineering after attending the showcase event

potential activities could also be developed in the future. For example, a virtual or in-person panel with current graduate students would provide BSP students another opportunity to connect with graduate students and provide a platform for them to ask specific questions about college, graduate school, and biomedical research. We could also help design and implement in-class activities to coincide with other lessons already being taught within the BSP courses. Ideas such as these will strengthen the relationship between WashU and PHS and provide a continuous source of opportunities for high school students to learn about biomedical engineering and for engineering graduate students to practice their science communication and mentoring skills.

In addition to developing more activities and events, another way to strengthen the relationship between WashU and PHS is to increase the number of labs at the university that are involved. In order to increase the number of PIs that are involved in this program, we will continue this partnership and each year invite more labs to participate which will increase the number of opportunities PHS students have to conduct research in WashU labs. We will also increase the number of graduate students that participate in the campus visit and showcase, further broadening the areas of research the PHS students are exposed to and creating a larger network of potential mentors for PHS students. WashU is comprised of a diverse population of graduate students, and encouraging graduate students of all backgrounds to connect with high school students will demonstrate that they belong in this field and that anyone can succeed in STEM.

The true depth of success from outreach opportunities, such as the ones we've highlighted here, will not be immediately known. It could potentially take several years for a full picture on success to come into focus as the participating BSP students complete high school and continue to postgraduation opportunities (e.g., higher education, trade schools, jobs, etc.). We anticipate that increased participation in outreach activities amongst underclass students (e.g., Opportunity 2) will lead to an increase in the number of seniors in the BSP. More senior BSP participants would mean that more students are continuing with the BSP from year-to-year rather than leaving the program for more traditional courses.

Along with future growth comes the need to address current "limitations" of the relationship. Although the vast majority of the postvisit surveys had positive comments, there was also a comment that suggested that "lab demos [could be] more hands on." Ensuring that all activities include a hands-on component is our goal in the future to increase interest and excitement around the first two opportunities discussed. High school students engage with presentations on a deeper level when they are able to participate with the demonstration; thus, we are requiring participants in future showcases (Opportunity 2) to incorporate a hands-on component to their demonstration to bring to PHS. It's our hope that by requiring more interactive demonstrations that students will enjoy the opportunity more and leave with a deeper understanding of biological engineering topics. With that, we need to determine how to conduct a second annual showcase with enough new information that students who attended previously (e.g., underclass students who are now a year older and still in the BSP) will remain engaged and learn something new. This effort will need to recruit a larger group of graduate student volunteers to present their work so there are new topics presented.

Another major goal we would like to achieve is increasing student participation with our Opportunity 3, namely, data collection on WashU campus for senior students. Based on feedback, we have students who are interested in collecting data in partnership with a WashU lab. However, logistical challenges have included (1) finding labs willing to host/sponsor high school students, (2) traveling between PHS and WashU during school hours, and (3) completing required tasks before students can participate in research at WashU (i.e., training for lab staff allowing minors to work in lab spaces, obtaining access to lab training modules for non-WashU affiliated students). Our hope is that over time we will be able to streamline the process of having high school students work in our lab and, by doing so, remove many of the hurdles that other labs are initially hesitant to tackle. We also aim to increase the overall number of students participating in the BSP. In order to accomplish this, we could meet with 8th grade students before they attend PHS to introduce them to the BSP and to STEM research, which would likely increase the likelihood of their choosing to participate in the program. Finally, we aim to expand the program beyond PHS to build relationships with other high schools in the area, increasing the number of students we can connect with and helping to spread STEM education and science communication to a wider audience. There are ample opportunities for this partnership to develop and grow with potential changes to current activities or the development of new activities.

The relationship between the Biomedical Sciences Program at Pattonville High School and our lab at Washington University has been beneficial for both PHS students (who have had the opportunity to see engineering research in action while also broadening their knowledge of career paths within the biomedical field) and WashU graduate students (who have been able to practice their science communication skills and share their research with a wider audience). Senior PHS students have been able to visit multiple biomedical engineering research labs over the past 2 years; graduate students from a variety of mechanical and biomedical engineering labs visited all BSP students at PHS to discuss and showcase their research; and one senior student conducted research in out lab for her senior capstone project. During these experiences, students saw firsthand how specialized research topics can be and how impactful the research is to STEM fields. These visits have created a paradigm shift in many students' thinking as they realize that there are more ways to impact the healthcare field than just practicing medicine. Students often come into the BSP at PHS with the idea of being a doctor, nurse, or pharmacist knowing they want to make a difference within the healthcare field but have a limited view of what that means. Our relationship has and will continue to allow students to evaluate and adjust their career goals and have a much broader view of biomedical sciences that includes cutting-edge research in engineering.

> "The partnership between the biomedical sciences program and Dr. Lake's lab has been positive and rewarding as an educator. Through effective communication, Dr. Lake and his lab mates have made it easy to coordinate high quality learning experiences for my students. I have seen my students' aspirations grow to new heights as a direct result of our partnership."
>
> –Jamie Jobe, PHS Educator

In conclusion, a partnership has been successfully developed between a university and a biomedical science program at a local high school. Several important lessons have been learned, which could be beneficial for the development of similar partnership programs elsewhere. First, it is crucial to connect with an educator or PI that is enthusiastic about the idea and will take on an active role in designing, planning, and implementing the various events. Second, the relationship between the university and the high school can be developed incrementally over time. For example, we implemented Opportunity 1 for 2 years before adding Opportunity 2, which made planning more manageable and resulted in the relationship being well established prior to attempting a more ambitious event such as the showcase. Third, it's important to maintain open communication between the two participating groups. With consistent communication, thoughtful goals and ideas can be easily shared between university and high school partners. Lastly, obtain feedback from students and other participating groups to evaluate and gauge the success of each opportunity/event and inform plans for future years in order to build a successful long-term partnership. We hope that groups at other universities will also build relationships with high schools in their area so that together as STEM professionals we can continue to engage with and enrich future generations.

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Data Availability Statement

The authors attest that all data for this study are included in the paper.

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