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Integrating Cardiovascular Engineering and Biofluid Mechanics in High School Science, Technology, Engineering, and Mathematics Education: An Experiential Approach

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Science, technology, engineering, and mathematics (STEM) education workshops and programs play a key role in promoting early exposure to scientific applications and questions. Such early engagement leads to growing not only passion and interest in science, but it also leads to skill development through hands-on learning and critical thinking activities. Integrating physiology and engineering together is necessary especially to promote health technology awareness and introduce the young generation to areas where innovation is needed and where there is no separation between health-related matters and engineering methods and applications. To achieve this, we created a workshop aimed at K-12 (grades 9–11) students as part of the Summer Youth Programs at Michigan Technological University. The aim of this workshop was to expose students to how engineering concepts and methods translate into health- and medicine-related applications and cases. The program consisted of a total of 15 h and was divided into three sections over a period of 2 weeks. It involved a combination of theoretical and hands-on guided activities that we developed. At the end of the workshop, the students were provided a lesson or activity-specific assessment sheet and a whole workshop-specific assessment sheet to complete. They rated the programs along a 1–5 Likert scale and provided comments and feedback on what can be improved in the future. Students rated hands-on activities the highest in comparison with case studies and individual independent research. Conclusively, this STEM summer-youth program was a successful experience with many opportunities that will contribute to the continued improvement of the workshop in the future. [DOI: 10.1115/1.4064822]

Introduction

The focus of educational research and innovation toward the science, technology, engineering, and mathematics (STEM) disciplines over the past two decades has shed light not only on the need for additional work in this direction but also on the various factors that directly and indirectly affect a student's decision to pursue a STEM-related disciple as well as their success. Applying STEM practices in education is important for the United States' economic growth and reliability [1]. Integrating STEM-related practices early on in elementary, early childhood, and high-school education is an important approach to promote interest in this field and encourage students to pursue their careers in these different areas. Outside of the varying practices of the educational system, in the United States, data show a significant number of outlying factors that play a role in the success of students when it comes to STEM education. Broader things such as gender, ethnicity, and socio-economic standing play a basic role in what kind of education students may receive while smaller things like family, culture, and neighborhood also play a role [1]. The quantitative assessment and evaluation of STEM teaching practices therefore present a significant challenge. It is hard to definitively say what programs may work best from school to school, as the type of schools may also play a role, or the population of students may affect whatever quantifiable data are taken away from the program results [2]. It is also hard to analyze data taken away from these STEM educational programs, as each program has its own scale and differing measurements of success. Success may be defined by the student's overall enjoyment, by simple testing scores, or by an assessment of a student's basic understanding of the course [3]. It should also be noted that testing scores could be viewed as an unreliable assessment of these programs. Essentially, it is very hard to measure the definitive success or even plain interest of individual students in STEM programs, as there are no real quantifiable ways to

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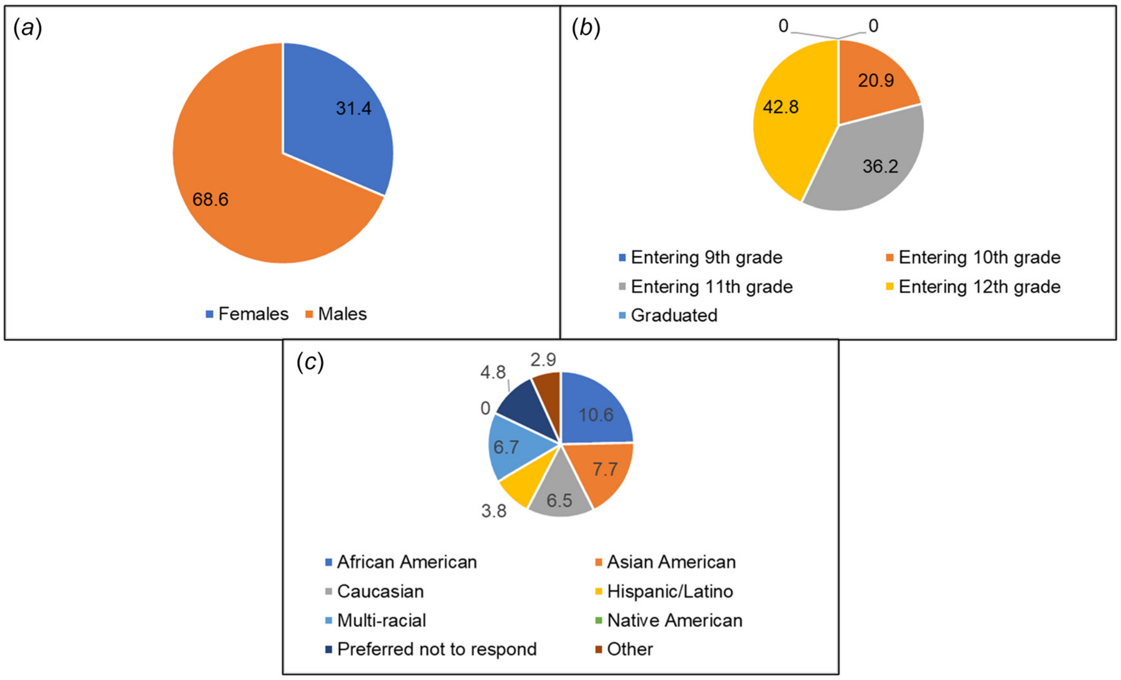

Fig. 1 Breakdown of the ESP 2023 program by (*a*) sex, (*b*) grade, and (*c*) race

measure success without the overlaying sociological standings of the students. So, a great measurement of STEM departments can't be quantified by their testing score, and the participants' overall review of the program is what needs to be assessed [3].

The use of innovative educational and outreach programs at the middle- and high-school levels to further interest in the pursuit of STEM-related careers is not a new undertaking, and its efficacy has been conclusively demonstrated [4–7]. Moreover, the teaching of subjects such as anatomy and physiology to high school-age students contributes to an understanding of their own health and potentially opens doorways to further medical-related education. The inclusion of these topics within the curriculum can lead to the development of interest in three-dimensional modeling technology, hands-on biology dissections, or device design, among others. Such authentic learning experiences with real-world exposure and applications may help students to better understand the value of significant health literacy and allow them to create an understanding of the various pathways available within bio-engineering and medicine apart from traditional options [8,9]. To that end, we developed a 5-day workshop aimed at exposing students in grades 9 through 11 to cardiovascular engineering, cardiovascular physiology, and biofluid mechanics.

Various methods can be adopted to foster curiosity and interest in STEM disciplines, including the development of learning workshops. The integration of hands-on learning, interactive participation, and a good simulation of STEM academics is a great way to encourage students to continue their interest in such programs.

We developed a workshop with the objective of introducing K-12 (grades 9–11) students to cardiovascular engineering, cardiovascular physiology, and biofluid mechanics. This was carried out through a series of hands-on projects that aim to foster an understanding of how engineering, biology and medicine can be integrated. The workshop had four crucial objectives: (1) to provide a good introduction to the field of biomedical engineering, (2) to have students work hands-on and build creative models, (3) to have the students connect their own health and wellness to potential diseases, and (4) to allow students to learn how to conduct cohesive research independently. The pursuit of such goals in the context of a workshop outside of the traditional classroom setting, specifically in the context of building representative models, allows students to create a connection between the concepts they are learning and the greater real-world context, and may inspire curiosity. This introduction to free thought and hands-on work has the hope of leading students into individual research, a significant part of tertiary education at both the undergraduate and postgraduate levels and drives many STEM careers. The teaching of critical thinking and independent learning affords students the tools necessary to take the lead in and ownership of their education. Students who participate in their independent research are shown to have increased motivation, a greater understanding and awareness of a topic [8].

Workshop Design and Structure

A workshop titled "Exploring Cardiovascular Diseases and Therapies" was designed for high-school-aged students in grades 9–11, with the aim of introducing them to the world of cardiovascular engineering, cardiovascular physiology, and biofluid mechanics. The workshop took place at Michigan Technological University in Houghton, Michigan, as part of the Engineering Scholars Programs (ESP) and Women in Engineering (WIE) programs. ESP and WIE are subsidies of the Summer Youth Program (SYP) at Michigan Tech, which was established in 1972 and has been expanding ever since. Summer Youth Programs are week-long, residential academic experiences for students in grades 6–11. Each year, over 1000 students from around the globe converge on the Michigan Tech campus for hands-on immersion. The SYP is not only attractive to the students of the Upper Peninsula of Michigan; students also travel from over 30 states and at least 10 countries to participate each summer. To learn more about SYP, please visit this reference.[3]

Briefly, the ESP in 2023 included 105 total participants (31.4% female), with the following educational distribution: 0% entering 9th grade, 20.9% entering 10th grade, 36.2% entering 11th grade, 42.8% entering 12th grade, 0% graduated. Their ethnic breakdown was as follows: 10.6% African American, 7.7% Asian American, 6.5% Caucasian, 3.8% Hispanic/Latino, 6.7% Multiracial, 0% Native American, 4.8% Preferred Not to Respond, and 2.9% Other. Figure 1 shows the breakdown by sex, grade, and race.

The WIE in 2023 included a total of 38 participants, with the following educational breakdown: 0% entering 9th grade, 18.4%

[3]www.mtu.edu/syp

entering 10th grade, 39.5% entering 11th grade, 42.1% entering 12th grade, 0% graduated. The breakdown by race was as follows: 5.3% African American, 7.9% Asian American, 84.2% Caucasian, 0% Hispanic/Latino, 2.6% Multiracial, and 0% Native American. Figure 2 shows the breakdown by grade and ethnicity.

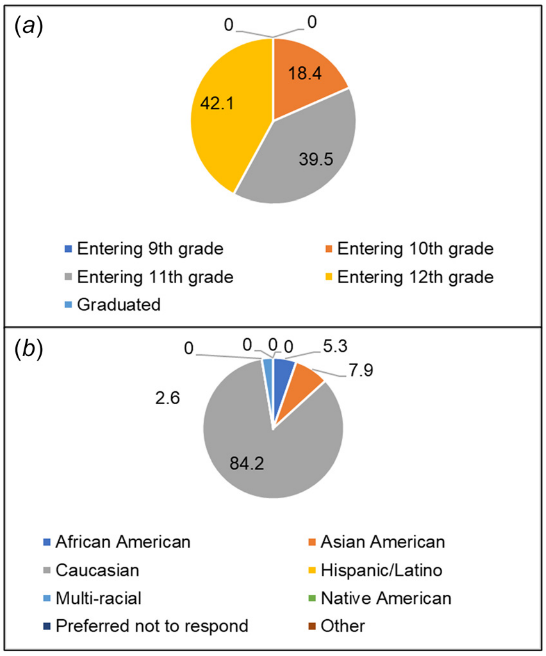

Fig. 2 Breakdown of the WIE 2023 program by (*a*) grade and (*b*) race

Eighteen students signed up for "Exploring Cardiovascular Diseases and Therapies," which took place over 5 days. Students were divided into three different groups, with a class of students in the morning, a class later in the afternoon and a third class in the week after in the morning. The gender, school grade, and ethnic breakdown of the participants in this workshop are shown in Figs. 3 and 4, for the ESP and WIE, respectively.

Day 1. Students were introduced to the anatomy and physiology of the heart and cardiovascular system through an informative PowerPoint presentation. Students were provided resources, such as doodle notes and color crayons, to take notes and annotate through color coordination, with the goal of enhancing student engagement. During the activity, the different structures of the heart and the cardiovascular system were explained, and students were subsequently introduced to valve disease, treatment approaches, after-effects of cardiovascular treatments, and congenital heart defects. This activity aimed to provide comprehensive exposure to cardiovascular structures, diseases, and therapies, and resources were purchased from TeachersPayTeachers [10].

Day 2. The second day consisted of hands-on activities. Bovine and porcine hearts were donated by Copey's Butcher Shop (Dayton, OH), and students were led through a dissection procedure. The lab was prepared before the student's arrival for both sessions. Students were instructed on the proper use of laboratory scalpel and shown where to bisect the heart in order to view its internal structures, introduced the previous day.

This exercise empowered students to connect their annotated notes taken on day one and apply their knowledge to the day two hands-on dissection activity. They also made comparisons between heart structures across species (e.g., porcine versus bovine), and

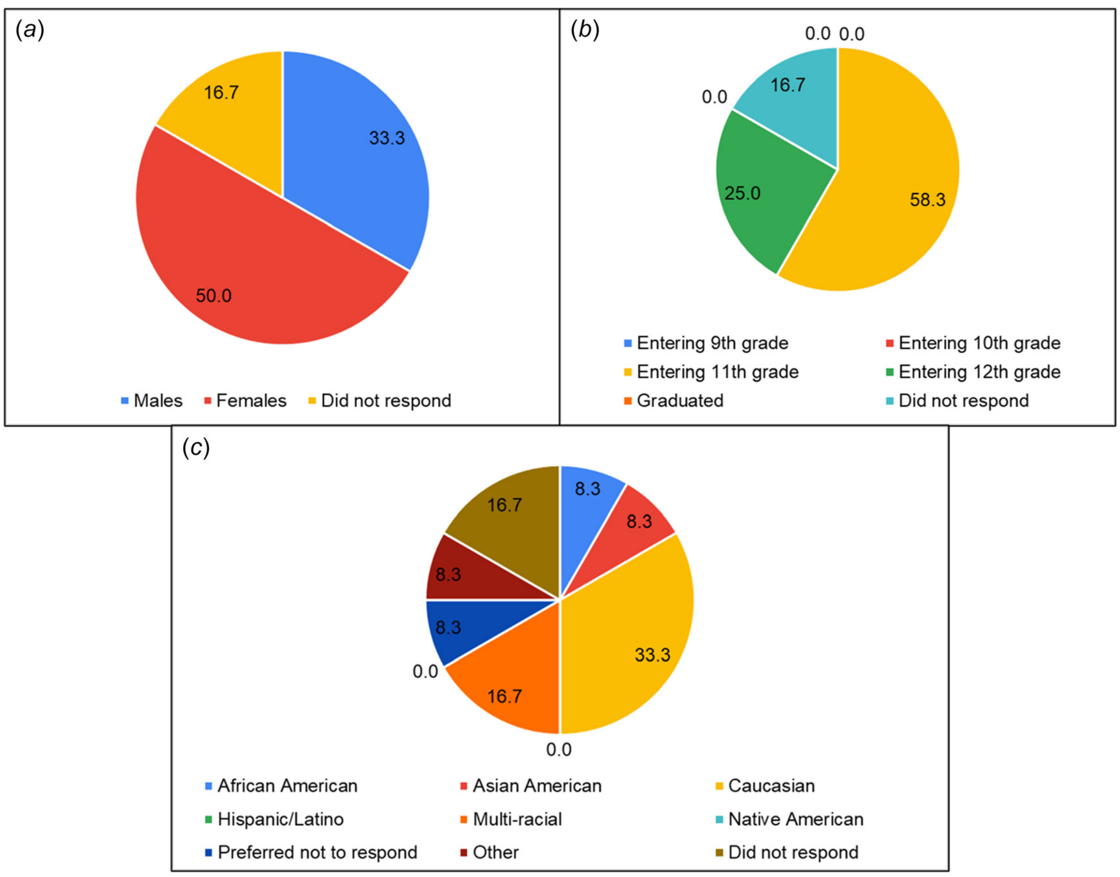

Fig. 3 Breakdown of the ESP 2023 "Exploring Cardiovascular Diseases and Therapies" program participants by sex, grade, and ethnicity

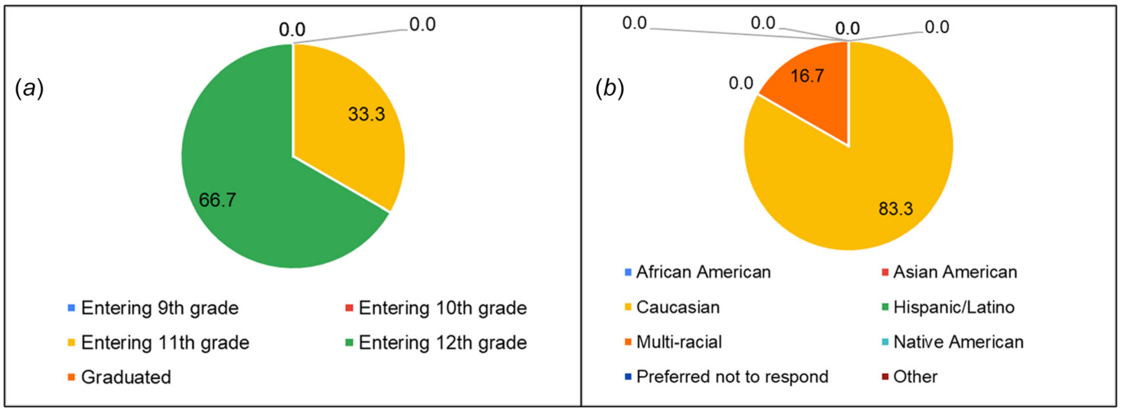

Fig. 4 Breakdown of the WIE 2023 "Exploring Cardiovascular Diseases and Therapies" program participants by grade, and ethnicity

were able to physically assess the material properties of the septum, ventricle, valve leaflets, and chordae tendineae.

Day 3. Students were given handouts that detailed the steps to build a simple heart simulator made from bottles, water and dye, and straws, then left to independently build a prototype. The purpose of the exercise was to better show and explain the mechanisms of flow transfer through the left or right sides of the heart and to the aorta or pulmonary artery. Additionally, the activity aimed at introducing students to in-vitro research [11–13]. Through this activity, students were able to also display figuratively how fast the heart beats to effectively pump blood through the system. The resources for this activity were purchased and well-documented on TeachersPay-Teachers [10]. Figure 5 shows a diagram of this setup in addition to a photograph obtained from the workshop. Briefly, the user needs to apply pressure or squeeze the middle bottle B (ventricle). To simulate the atrio-ventricular valve action, the user needs to pinch the straw between bottle A (atrium) and B (ventricle). Due to the succession of squeezing and pinching actions, the fluid will flow to bottle C (that represents the body or lungs). While keeping bottle B contracted, the user can also pinch the straw located between bottle B and bottle C, then release bottle B to see how the fluid flows from bottle A to bottle B.

Day 4. Students were led to the computer labs on campus and independently conducted problem-driven based learning through a provided case study based on the work of Schwarz et al. [14]. The case study was modified to accommodate the background of K-12 students and altered in such a way as to use more clinical resources for diagnosis and classification. The students were given a handout regarding aortic stenosis as an undiagnosed disease and were guided to websites and academic manuscripts to assist with their research. The goal of this activity was to have the students use these resources to understand the symptoms of the given disease in the case study, and to classify its severity based on the current clinical guidelines. A secondary goal of the activity was to familiarize students with independent literature review, as it plays a role in all STEM-related fields.

Day 5. On the final day of the workshop, students gathered outside to perform experiments related to basic blood composition and rheology. Students were instructed to prepare mixtures of water and cornstarch. Then, they were led through a tactile evaluation of the mixture, a mechanical evaluation through shear force variation, and comparative evaluation of the mixtures to known substances such as water and honey. The students were asked to draw the shear stress–shear strain curve of the honey, cornstarch mixtures, and blood. This experiment was an introduction to the concepts of Newtonian and non-Newtonian fluids and explains where blood falls categorially.

Assessment and Outcomes

Our assessment survey included Likert and open-ended questions to measure students' interest in biomedical engineering. We also included additional questions specifically designed to acquire

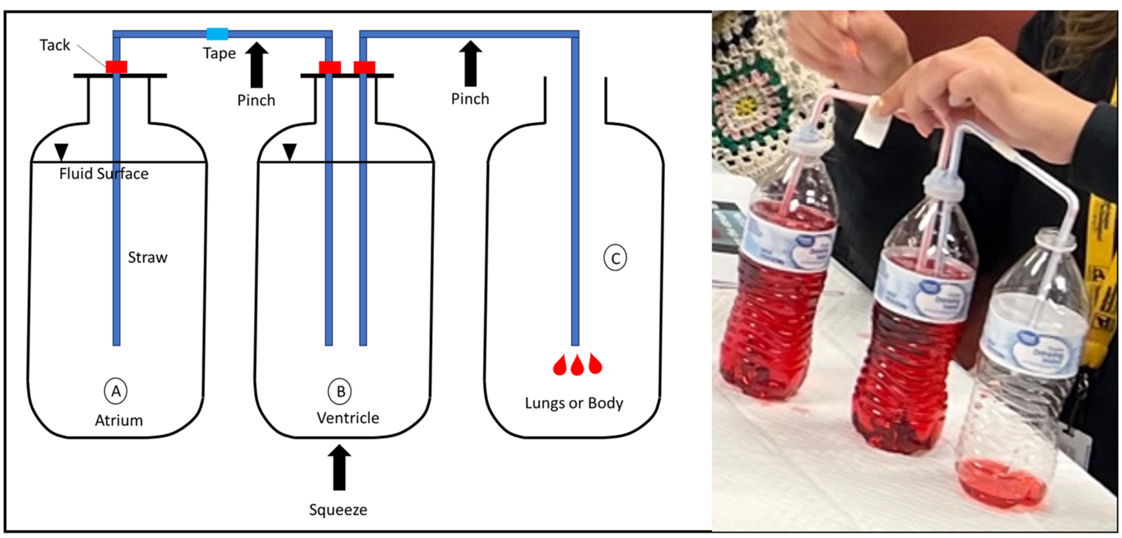

Fig. 5 Schematic diagram and image of the simple flow loop activity performed on Day 3

Table 1 List of questions that were given to the students to assess the workshop

List of questions in the survey
1. On a scale from 1 to 5, 5 being the highest, rate this workshop in general.
2. Using the same scale, rate each class:
Day 1: Introduction to the heart and cardiovascular system
Day 2: Heart dissection
Day 3: Mock circulatory flow loop
Day 4: Case study
Day 5: Blood rheology
3. What was the aspect that you liked the most about the classes?
4. What was the aspect that you liked the least about the classes?
5. How do you think this program can be improved?
6. Was this program what you expected? Please explain.

feedback for formative improvement. For example, the participants in this workshop were asked to highlight what aspects of the workshop were most beneficial as well as how they could be improved.

On the evaluation sheet, students indicated the days of the workshop that they enjoyed and briefly described their general growth of knowledge. Students rated their overall experience on a scale from 1 (lowest) to 5 (highest). Table 1 shows a list of questions that were used for the workshop assessment. All ratings were in the 4 (38.9%) and 5 (61.1%) range (Fig. 6(*a*)). Students were then asked to rate their enjoyment of the five individual classes given throughout the week, rating them on the same scale from 1 to 5.

The assessments of the individual classes have a broader spectrum of rating compared to the overall rating. Many students commented on already having an accumulation of knowledge in concerns to the heart and anatomy, due to school or their own interests. So, the first introductory day to the heart and the cardiovascular system were therefore rated lower, with only 44.4% of students rating it a 5 (Fig. 6(*b*)). But, as shown by Fig. 6(*c*), day 2 with the hands-on learning experience (dissection) was rated highest. Many students wrote comments about enjoying this aspect of hand-on learning and commented on how it helped them in the transition of knowledge from day 1 to day 2 during the dissection. Over 8 of the 18 students commented that the hands-on learning aspect of the workshop was unique in that they may not get it in a day-to-day class setting.

Regarding day 4, the majority of the students gave a five rating to it with 5.6% giving a rating of 2 (Fig. 6(*d*)). From the written comments provided by students, some mentioned that they did not understand well how a connection between the experimental setup and the in vivo system can be established. Despite the students' comments about not enjoying the individual and independent study/case study, the majority of students assigned a five rating to it, with 44.4% of students rating it a perfect score of 5, as shown in Fig. 6(*e*). With respect to day 5, 44.4% of students assigned a five rating to it (Fig. 6(*f*)). Students generally stressed that they enjoyed the dissection and the blood rheology experiment due to their hands-on aspects.

At the end of the students' individual assessments, they were asked how the workshop could be improved. Most of the comments were regarding the students wanting to learn more and being given an opportunity to learn more through lab tours, more experimental work like dissections, and the opportunity to learn about more biomedical devices concerning the heart and cardiovascular system.

Evaluation of the Workshop's Success in Promoting Interest in Cardiovascular Engineering and Science, Technology, Engineering, and Mathematics. One of the objectives of such hands-on learning workshops is to improve student eagerness for the STEM disciplines and to stimulate their desire for learning. Studies have consistently shown that hands-on learning in the classroom not only results in increased motivation, but also improved self-efficacy [15,16]. Experiential learning, which includes not only physical activities but also more abstract applications such as computer simulations, and case studies, among other activities, have been shown to increase critical thinking skills and provide a more comprehensive understanding of the material taught. Students consistently show a greater mastery of the content (as compared to lecture-style approaches), and this process emphasizes the learner rather than the lecturer. In their 2011 article, Grandzol and Wynn emphasized that students who enjoy the learning experience and recognize the importance of what they are learning are more likely to challenge themselves beyond what is required. Learning is an inherently emotional experience—creating a supportive environment in which students are encouraged to be curious and creative fosters enthusiasm and encourages a deep approach to develop one's own understanding and retain knowledge [17]. Among even younger students (5th graders), Gerstner and Bogner showed that, although a teacher-centered approach provided better short-term results, hands-on instruction resulted in greater long-term retention rates along with high scores in perceived competence, perceived choice, and interest [18]. Grandzol and Wynn were able to show the advantage of hands-on learning over lecture-style delivery on parameters such as retention, content knowledge, motivation, and enjoyment, assessed through surveys and "pop" quizzes [19].

Our workshop encouraged universal learning principles that emphasized the experiential approach. Students were provided background knowledge and engaged in a discussion regarding the

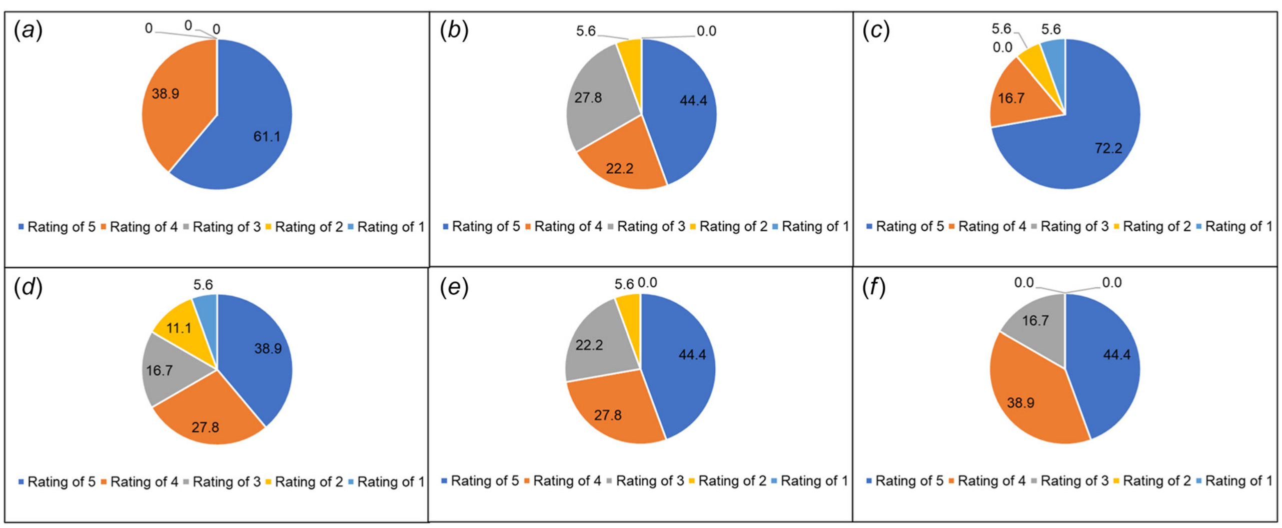

Fig. 6 (*a*) Breakdown of the ratings of the whole workshop and (*b*)–(*f*) breakdown of the ratings of each individual day going from day 1 to day 5, respectively. A rating of 5 was the best and a rating of 1 was the worst.

clinical applications of this knowledge. The remaining time was spent in experiential activities to encourage collaboration and communication, as well as to encourage self-efficacy. By interacting with clinically applicable tools and techniques such as heart dissection, computational modeling, and review of the literature at the high-school level, students are able to see the fruits of their labor—similarly, various studies have shown the effectiveness of STEM programs such as robotics on promoting student interest in a STEM-related career [20–25]. Such studies are by no means new—educators such as Bill Nye and Mark Rober have long employed visual models of the active learning approach by showing the physical effects of principles they wish to teach, inspiring generations of children to pursue STEM-related studies or careers.

We also observed similar results in our workshop where students connected the dots and showed a better understanding of principles after they completed the hands-on tasks such as the dissections, the flow loops, and the rheological assessment. In addition, the discussion opportunity that the case study provided was invaluable. The students were engaged and enjoyed learning not only about the disease and therapy but also about the tools that are used in clinic for diagnosis (such as the STS score calculator that they used for the case study).

Conclusion

Science, technology, engineering, and mathematics education programs are growing more adaptive each year and are incredibly important for bettering the education of coming generations. The workshop run was meant to teach K-12 (grade 9–11) students about the area of cardiovascular engineering, cardiovascular physiology and biofluid mechanics. The workshop consisted of hands-on activities and theoretical concepts distributed over a period of 15 h in total. Students were left to rate each individual lesson taught throughout the workshop and the whole workshop and make comments about parts of the program they appreciated the most and parts they thought could be improved for the next workshop. When asked about their overall enjoyment of the workshop students were left to rate it on a scale from 1 to 5, 1 being the worst and 5 being the best. No students rated the workshop below a rating of 4, with the majority rating the program a 5. Students continued to rate each individual day on this scale, continuously rating more hands-on interactive activities higher than more individually lead activities. They also commented on their enjoyment of the hands-on activities, noting it later in their assessments. STEM education plays an integral part of economic growth and reliability, and programs lead students to have interests in STEM related fields and jobs. Well-formed STEM education programs can be a good introduction to science, technology, engineering, and mathematics for many students, and may encourage them to continue to pursue their careers in these fields.

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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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