Biomedical Engineering Education
https://doi.org/10.1007/s43683-025-00199-1

INNOVATION ARTICLE

Observations on the Influence of Experiential Teamwork and Competitive Activities on Student Perceptions, Engagement, and Motivation in the Context of a K-12 STEM Workshop

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Received: 19 November 2024 / Accepted: 25 August 2025

Abstract

Purpose This study aimed to evaluate the impact of active learning and competition on student engagement, motivation, and learning in a STEM-focused summer workshop. This was achieved through exposing K-12 high school students to experiential activities related to concepts within the realm of medicine and engineering. The research question asked was whether these instructional approaches could enhance student interest and effectiveness in understanding complex biomedical and engineering concepts and achieving the intended goals.

Methods The workshop, conducted at Michigan Technological University, involved four distinct classes: Wound Healing, Robotic Arm Construction, C-section Simulation, and Engineering Design. Each class included an interactive lecture, a teamwork activity, and a competitive component. Student engagement, motivation, and perceptions of the teaching style were assessed through questionnaires, and statistical analysis was performed to identify significant differences across the classes.

Results The study showed that the Wound Healing and Engineering Design classes, which fostered positive peer interaction the most along with longer time to achieve the tasks, led to higher student engagement and motivation compared to the Robotic Arm and C-section classes. Significant differences were observed in how students perceived the teaching style, with Wound healing and engineering design classes showing more effective instructional approaches. The variability in responses obtained suggests that while competition and active learning were helpful, their effectiveness depended on the complexity and structure of the activities and their relevance to the students' interests.

Conclusion STEM workshops for high school students are most effective when they balance active learning with structured competition, align task complexity with appropriate pre-scaffolding, and incorporate clear, collaborative goals. Future educational strategies should focus on using instructional approaches that aim to align the expectations of students with those of the instructors in order to maximize the effectiveness of STEM outreach programs.

Keywords STEM education · Active learning · Competition · Student engagement · Instructional methods · Teamwork · Biomedical engineering · K12 outreach

Introduction

The Importance of STEM Education and Challenges

Science, technology, engineering, and math, commonly grouped as the STEM disciplines, represent a broad range of fields whose very definition is inconsistent depending on country, government institution, educational level, and many other factors [1]. According to the Pew Research Center, of the 37 Organization for Economic Cooperation and Development (OECD) member countries, the United States ranks below average in math (28th) but above average in science (12th), when comparing 2022 Program for International

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Published online: 10 September 2025

Student Assessment (PISA) scores [2]. While it should be noted that standardized test scores have been shown to be unreliable narrators in characterizing the full scope of the educational setting and educational achievement [3], such results, and trends in the wrong direction, present cause for concern. Moreover, while the number of individuals in the STEM workforce in the United States increased by 20% between the years 2011 and 2021, ethnic and gender disparities continue to persist, with females representing only 35% of the STEM workforce in 2021, as compared to 32% in 2011 [4]. Because self-efficacy is directly related to performance in a specific task, individuals with higher self-efficacy have been shown to exhibit more extensive engagement [5] and to perform better and persist longer in any discipline of interest, including STEM [6].

Active Learning vs. Passive Learning

Active learning is an instructional approach that actively involves students in the teaching and learning process in order to encourage them to take ownership of their education while fostering interest, self-efficacy, and long-term retention. Bonwell and Eison [7] first conceptualized active learning as a strategy that requires students to engage in activities beyond passive listening, such as discussions, problem-solving, and hands-on experiences. Later studies emphasized and demonstrated the effectiveness of active learning, particularly in STEM education, by demonstrating increased student engagement and conceptual understanding when compared to traditional lecture-based instruction. For example, Gerstner and Bogner [8] found that integrating hands-on consolidation phases such as concept mapping significantly improved students' cognitive achievement and motivation in science classes. Similarly, Grandzol and Wynn [9] explored how team-based and experiential learning methods in business education led to greater student retention and motivation. This highlighted the broad applicability of active learning across disciplines. More recent studies have quantified these benefits, with meta-analyses showing that students in active learning environments exhibit higher performance and self-efficacy than those in passive learning settings. Putro et al. [10] further emphasized the connection between active learning and student motivation, demonstrating that inquiry-based and hands-on methodologies directly correlate with higher engagement and problem-solving skills. In the context of biomedical engineering education, Schultz et al. [11] identified team-based pedagogy as a key driver of student participation, therefore supporting the integration of collaborative and competitive elements in classroom settings. Such activities are particularly powerful when employed within the STEM disciplines and may encompass a variety of approaches—problem-based, collaborative, cooperative, experiential, among others [12, 13]. This study builds upon these findings by incorporating experiential teamwork and competitive learning activities to assess their impact on student engagement, motivation, and STEM interest in a K-12 outreach setting. By structuring each workshop session around interactive lectures, collaborative activities, and competitive challenges, we aim to evaluate whether these instructional methods can enhance learning outcomes, teamwork effectiveness, and student enthusiasm for biomedical engineering concepts.

Learning of the STEM disciplines requires both retention of information as well as stimulation of deeper critical thinking, a combination that may prove challenging in a traditional, passive lecture environment [14, 15]. The goal of active learning strategies is to foster psychological safety, improve self-efficacy, and empower students to think beyond the lecture slide or the textbook by actively seeking and challenging sources of information to become active participants in the expansion of their own knowledge [16, 17]. Jesokova et al. found that implementation of inquiry-based science education in the secondary school environment over a 3-year period improved student inquiry skills by approximately 8%, greater still among male students [18]. STEM-related work requires intimate interaction with the scientific method, including the development of research questions and hypotheses, identification of relevant variables, and the development of techniques to isolate the effects of the variable (s) of interest. The goal of STEM education is therefore greater than the simple retention of information—the requirement of higher-order thinking also teaches students how to seek out information and evaluate its reliability, as well as how to create the knowledge they are not able to find [19]. Simply put, an additional goal of STEM education is to learn how to learn—taking ownership of one's learning through active approaches is particularly powerful in the STEM disciplines [15].

STEM Education in the K-12 Setting

Within biomedical fields, although also generally true for the STEM disciplines as a whole, the use of innovative outreach programs encouraging experiential learning has shown promising results [20–22]. For example, Burns et al. [20] developed a "train and equip" model for middle school cancer education that boosted teacher and student confidence in science topics. Cregler et al. [21] demonstrated that early enrichment programs for minority students successfully increased biomedical career interest, which aims to build STEM pipelines at a young age. Radke et al. [22] showed that immersive hands-on STEM workshops are highly effective in engaging high school students, in order to increase their motivation and self-confidence in STEM. The inclusion of these outreach activities within the primary and secondary school curriculum has been shown to increase interest, motivation, and self-efficacy in STEM-related disciplines [23–29]. Kuchynka et al. [23] found that a 4-week geoscience outreach program for high school students significantly increased participants' STEM self-efficacy and intentions to pursue STEM. Zhang et al. [24] demonstrated that integrating STEAM and Maker education—a new type of educational practice which aims to foster creativity—into the curriculum led to positive changes in students' learning motivation and self-efficacy, which supports interdisciplinary knowledge acquisition. The implementation of active learning programs aimed at promoting critical thinking and design thinking through hands-on (experiential) activities has consistently shown a reported increase in self-efficacy, particularly among young girls [30–32]. For instance, Demetry et al. [32] showed that hands-on middle school engineering outreach programs for girls led to positive trends in improving or developing STEM identity and increasing college enrollment in STEM majors.

Competition in the Learning Environment

Competition in the learning environment can carry negative connotations, and if not handled carefully, result in adverse consequences. Competitive activities provide extrinsic sources of motivation beyond grading, and foster cooperation and collaboration by promoting the basic elements of positive interdependence, individual accountability, promotive interaction, social skills, and group processing [33–37]. Competition in the work environment is unavoidable—when fostered in a constructive manner and by implementing the appropriate conditions for cooperative learning, the addition of competition to classroom activities can prove to be an additional tool to increase student engagement, interest, and motivation [38]. Group activities can serve to shift the incentive of participation to group goals rather than solely individualistic goals; in doing so, they can encourage all students to participate and claim a stake in group performance without the added anxiety of individual participation in class discussions.

Healthy and Unhealthy Competition in the Learning Environment

Student perception plays a large role in the effectiveness of competitive elements within the classroom. If students perceive winning to be largely important, the goals to be largely unattainable, and the rules to be unclear, then competition is more likely to foster frustration and disengagement [38]. In their 2010 study, Wang and Yang even went further to state that evaluation based on relative performance strengthens the connection between performance and perceived ability and may shift to a loss-aversion strategy of winning "by not losing" [39], further supporting a strategy of group collaborative competition rather than individualistic competition. Moreover, student perception of instructor and educational mindset beliefs has been shown to be more significant than the instructor's personal belief and/or endorsement [40].

Goals of This Workshop

While this workshop was originally designed as an outreach effort to introduce K12 students to biomedical engineering, post-event evaluations revealed recurring themes related to engagement, teamwork, and motivation that warranted deeper reflection. Instead of testing a formal hypothesis, this retrospective analysis—using existing data—aimed to share through our experience how the combination of active learning and structured competition can affect students' perception of learning and interest in STEM. By reporting these observations, we aimed to contribute to the growing literature on experiential learning in pre-college contexts and offer guidance to others who implement similar outreach efforts. Having said that, active learning has been widely proven to significantly improve student engagement, retention, and motivation in STEM education [14]. Additionally, competition when thoughtfully implemented, can enhance motivation and engagement in STEM by encouraging students to challenge themselves and collaborate more effectively within teams [41, 42]. Despite some concerns that competition may hinder some learners, prior studies indicate that structured, goal-oriented competitive tasks can enhance students' connection to the material and encourage meaningful participation in group-based science activities [43]. Thus, the aim of this workshop was to evaluate how experiential instruction that combines elements of active learning and structured competition may shape students' perceptions of engagement, teamwork, and interest in STEM, and to identify which elements were most effective or needed refinement for future outreach efforts.

Materials and Methods

A summer workshop entitled "Fostering healthy competition in a learning environment in Biomedical Engineering" was designed for rising secondary students in grades 9 through 12, aimed at introducing these students to concepts within the realm of biology, medicine, and engineering. The workshop took place at Michigan Technological University in Houghton, Michigan as part of the TRIO Upward Bound Summer Program. The TRIO Upward Bound Summer Program is a community-based program, funded through the U.S. Department of Education, that aims to empower first-generation students and students who come from income-eligible households as per the

Federal Income Eligibility Requirements. On average, the TRIO Upward Bound serves 84 participants from Baraga, Houghton & Keweenaw counties in the Upper Peninsula of Michigan.

The workshop consisted of four 2-h classes of activities spanning a 4-week period, and attending the workshop in full (4 days) was mandatory for all the registered students. The study was reviewed by the Michigan Technological University Institutional Review Board (IRB) and was deemed exempt from full review. A total of 25 students registered for the four-day workshop. Snapshots from each class are shown in Fig. 1. A summary table (Table 1) of these classes is provided below.

Day 1: Wound Healing

Interactive Lecture: Students were exposed to an interactive lecture introducing them to skin, wounds, the basics of wound healing, and the role of wound closure techniques (i.e., suturing, stapling) in promoting the healing process.

Teamwork Activity: Students were divided randomly into groups of 4 and provided suture practice pads purchased through Amazon. Groups were visited individually by a session instructor and taught basics principles of simple interrupted sutures for the closure of cutaneous wounds. Groups were then allowed to practice with teammates on the provided suture pad. Students were encouraged to work

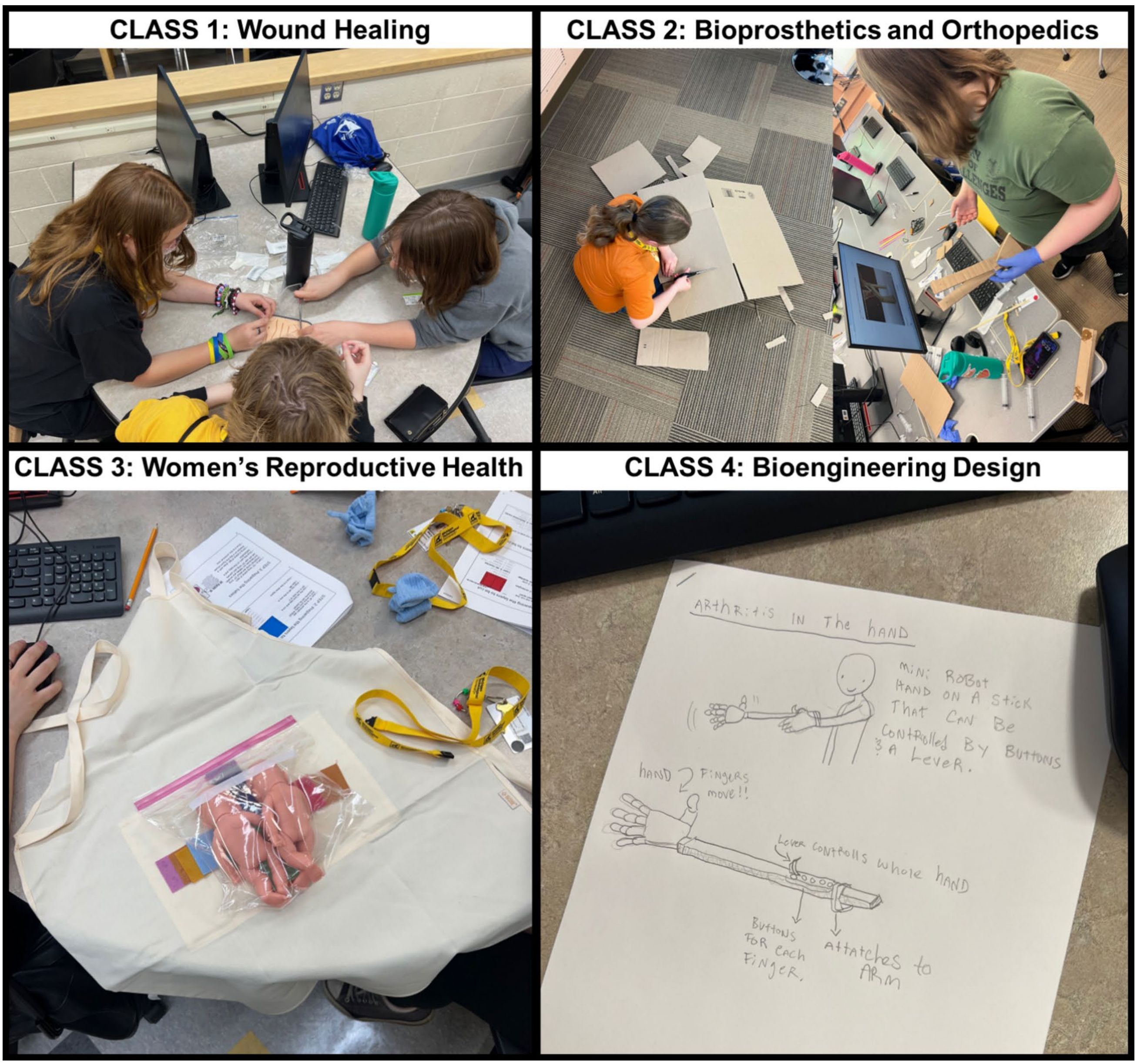

Fig. 1 Snapshots from each day of the MTU TRIO 2024 workshop

Table 1 Summary of classes and their descriptions along with the number of students who participated and submitted an evaluation

Class	Description of activities	Number of students
Wound Healing	Students learned about skin, wounds, and wound healing techniques such as suturing and stapling. They practiced simple interrupted sutures on suture pads in teams and then participated in a timed competition to close wounds as efficiently as possible.	23
Bioprosthetics and Orthopedics	Students explored bioprosthetics and orthopedics, focusing on robotic arm construction by following a step-by-step tutorial video. They worked in teams to construct the robotic arm using provided materials and competed based on completion, functionality, and teamwork.	21
Women's Reproductive Health	Students were introduced to women's reproductive health and childbirth challenges, focusing on C-section procedures. They participated in a simulated C-section exercise, following step-by-step guidelines, and competed based on technical execution, teamwork, and presentation.	21
Bioengineering Design	Students engaged in product design and development, learning about the engineering design process. They worked in teams to design assistive devices for arthritis or hemiparesis patients. Each team presented their design, with peer evaluation determining the rankings.	21

together and discuss during this time period, with instructors monitoring the room and providing assistance wherever necessary. Snapshots from the class are shown in Fig. 1.

Competition: Students were encouraged to remain within the same groups. These groups were then provided a fresh suture pad, with fewer pre-cut wounds than the practice pad, and given a 30-min time limit. In order to highlight both the importance of speed and accuracy in the clinical setting, groups were challenged to close all of the wounds on the competition pad as quickly as possible with as few stitches as possible. 10 points were awarded in each of the two categories, speed and timeliness, to the best-performing group in each category, and descending scores were awarded to subsequent performers. The group with the highest total score was declared the winner. The first- and second-place groups, as assessed by time and number of stitches, were then allowed to keep the suture pads as a prize.

Assessment: After the day's activities, students were asked to complete a questionnaire to assess their enjoyment of the course and their interest in the subject matter (Appendix 1).

Day 2: Bioprosthetics and Orthopedics

Interactive Lecture: Students were exposed to an interactive lecture introducing them to the basics of bioprosthetics and orthopedics, including types of devices, applications, and the needs of the field. Students were then shown a video of their construction challenge [44], described below, during which the instructor described the principles of hydraulic power as utilized in robotics and their application in the specific steps of this construction challenge.

Teamwork Activity: Students were divided randomly into groups of 4, ensuring that they did not work with any of the same students from Day 1. Students were provided the video shown during the lecture portion and challenged to follow the video using the provided materials in order to create a stable, hydraulic-powered robotic arm capable of moving small objects such as a soda can. Groups were encouraged to split the work between the four students in such a way as to complete the construction challenge within a period of approximately 75 min. Snapshots from the class are shown in Fig. 1.

Competition: Group performance was evaluated based on three factors: (1) level of completion of the assignment, (2) robotic arm task capability, (3) level of teamwork within each group. Scores were assigned for each category and added to come to a total score. The teams were then ranked by total score.

Assessment: After the day's activities, students were asked to complete a questionnaire to assess their enjoyment of the course and their interest in the subject matter (Appendix 2).

Day 3: Women's Reproductive Health

Interactive Lecture: Students were exposed to an interactive lecture that introduced them to the basic concepts of women's reproductive health, particularly childbirth, the challenges there, and the risks associated with childbirth procedures mainly C-section. The lecture was structured in a question/answer format to ensure that students are engaged in the lecture.

Teamwork Activity: The activity planned for this class was a C-section simulation that aimed to introduce students to the complexity of this abdominal procedure, to introduce them to the different layers that lead to the uterus, and to ensure that they manage to complete the procedure. Students were divided randomly into groups of 3, making 7 groups with 3 students each. They were handed handouts with detailed steps and guiding images to complete the C-section simulator. Groups were encouraged to split the work between the three students in such a way as to complete the simulator within a period of approximately 80 min. Snapshots from the class are shown in Fig. 1.

Competition: Group performance was evaluated based on three factors: (1) technical content, (2) presentation delivery, and (3) level of teamwork within each group. Scores were assigned for each category and added to come to a total score. The teams were then ranked by total score. Three judges graded independently the presentation of each team.

Assessment: After the day's activities, students were asked to complete a questionnaire to assess their enjoyment of the course and their interest in the subject matter (Appendix 3).

Day 4: Bioengineering Design

Interactive Lecture: Students were exposed to an interactive lecture that introduced them to the basic concepts of product design and development, the engineering design process and the commercialization plan. The lecture was structured in a question/answer format to ensure that students are engaged in the lecture. The lecture also comprised an outline of how the class will be conducted, as it was designed to have a different structure compared with the three previous classes.

Teamwork Activity: The activities planned for this class aimed to introduce students to product design, engineering design process, and commercialization. Students were divided randomly into six groups of three or four—depending on the numbers. They were divided into three teams per project. Two projects were proposed. The first project aimed to design a device that helps patients with arthritis do everyday tasks such as opening bottles easily. The second project aimed to design an at-home device that helps patients with hemiparesis consume their meals independently. They were handed handouts to write down and sketch their ideas. The total time assigned to complete this exercise was 75 min. At the end of the 75 min, each team was asked to present their design, identify their target users, their users' needs and their design process to the whole class. Snapshots from the class are shown in Fig. 1.

Competition: Group performance was peer evaluated. Project 1 teams ranked the performance of project 2 teams from 1 to 3, 1 being the best, and project 2 teams ranked project 1 teams from 1 to 3 as well.

Assessment: After the day's activities, students were asked to complete a questionnaire to assess their enjoyment of the course and their interest in the subject matter (Appendix 4).

Statistical Analysis

Student questionnaires for each class consisted of rating a set of questions on a Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree). Data was compared between questions and class days using parametric testing methods, specifically single-factor ANOVA testing among multiple groups, followed by post hoc two-tailed t-tests, as consistent with the general consensus for analyzing Likert data [45–48]. Due to the large volume of comparisons, relevant statistics are reported in the provided tables and highlighted in the text where appropriate.

Results

Enrollment Breakdown

The distribution of students by gender, ethnicity, and high school grade is shown in Fig. 2.

Evaluation Questionnaire

Student evaluation questions were categorized according to the major themes of Prior Interest, Motivation, Perception, Engagement, Teamwork, and Competition. Error! Reference source not found. (provided separately in its own document) shows the distribution of the evaluation statements within the themes and the results of the evaluation are reported as medians ± interquartile range (IQR) for each class day (Table 2).

Thematic Evaluation Results

Table 3 shows how our workshop classes align with the intended learning outcomes. While all our classes aimed to achieve some degree of engagement and teamwork, the achievement of specific course objectives varied depending on the structure, complexity, and relevance of the activities.

Prior Interest: Students began the workshop with low-to-moderate prior interest in most topics, especially for Women's Reproductive Health class. All sessions however were successful in raising student curiosity and confidence. Wound Healing and Bioengineering Design classes were the most effective in generating interest and increasing students' desire to attend future sessions. Supplementary Fig. 1 shows a detailed breakdown of the results based on this theme.

Perception: Instructor preparedness was rated consistently high across all classes. Wound Healing stood out for clear instruction and encouragement of peer interaction and engagement. Bioengineering Design also was rated highly due to its structure, clarity, and accessibility. Students were less satisfied with Bioprosthetics and Orthopedics class due to unclear expectations and perceived disorganization given a time limit. Supplementary Fig. 2 shows a detailed breakdown of the results based on this theme.

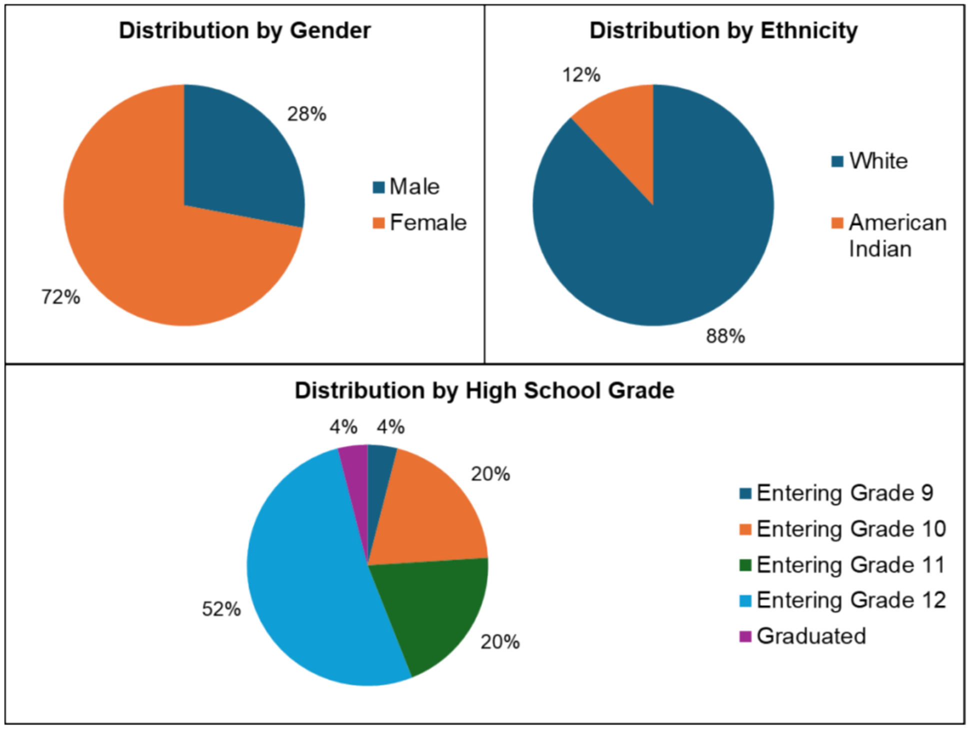

Fig. 2 Breakdown of the TRIO 2024 "Fostering healthy competition in a learning environment in Biomedical Engineering" program participants by sex assigned at birth, ethnicity, and high school grade

Engagement: Engagement was the highest in Wound Healing and Engineering Design classes, where activities were tangible, manageable given the time limit, and engaging. Bioprosthetics and Orthopedics class suffered from time pressure and complexity, while Women's Reproductive Health's class's engagement was affected by relevance and potential emotional disconnect for some students. Supplementary Fig. 3 shows a detailed breakdown of the results based on this theme.

Teamwork: Students appreciated working in teams across all sessions. Teamwork was seen as most beneficial in Wound Healing class, where guidance and individual roles were well defined. In Bioprosthetics and Orthopedics class, a lack of structure decreased effectiveness and contributed to frustration. Women's Reproductive Health class was positively rated for procedural collaboration. Supplementary Fig. 4 shows a detailed breakdown of the results based on this theme.

Competition: Students generally enjoyed the competitive elements in the classes, but only when clearly explained, divided into tasks, and achievable given a time limit. Competition in Wound Healing and Engineering Design classes increased motivation and focus. In Bioprosthetic and Orthopedics class, the pressure, time-dependence, and complexity led to frustration, whereas in Women's Reproductive Health class, competition outcomes felt less meaningful for some students. Supplementary Fig. 5 shows a detailed breakdown of the results based on this theme.

Discussion

This study evaluated whether the integration of active learning and competition in a STEM-focused summer workshop could enhance K-12 students' engagement, motivation, and perceived understanding of complex biomedical and engineering concepts. Through a series of experiential, hands-on activities that combined medical applications and engineering, we assessed how these instructional strategies influenced student interest and perceived learning outcomes. The findings suggest that when carefully designed and developmentally structured, such approaches can effectively lead to increased enthusiasm, confidence, and understanding among high school students participating in STEM outreach programs. All activities were designed with high school students in mind and planned by our team to ensure feasibility for a time-limited workshop format. However, any future prospective implementation would certainly benefit from a formal evaluation of developmental appropriateness to ensure that all students, regardless of background or familiarity with the subjects, feel included and engaged. Statistical comparisons are included in Supplementary Tables 1 and 2.

Prior Interest

Students started the workshop with low-to-moderate prior interest, particularly for the Women's Reproductive Health class. This was not a surprising observation given that students were not selected based on prior STEM interest and

Table 2 Median ± IQR of student evaluations of each questionnaire statement for each class day, broken down by theme

Statement	No.	Themes		Class 1		Class 2		Class 3		Class 4	
				Median	± IQR	Median	± IQR	Median	± IQR	Median	± IQR
I had prior interest in the material taught today.	1	Prior interest		3	± 2.0	3	± 1.0	2	± 2.0	3	± 2.0
Today's class increased my interest in the subject matter.	2	Motivation		3	± 1.5	3	± 1.0	2	± 3.0	3	± 2.0
The instructors appear to be well-prepared for today's class.	3	Perception		4	± 1.5	4	± 1.0	4	± 1.0	4	± 0.3
I feel more motivated to learn after today's class.	4	Motivation		4	± 1.5	3	± 1.0	3	± 2.0	3	± 1.0
Today's class included a traditional lesson delivery.	5	Perception		3	± 1.0	3	± 0.0	4	± 1.0	3	± 1.0
Today's class included plenty of teamwork.	6	Perception	Teamwork	5	± 1.0	4	± 1.0	4	± 1.0	4	± 1.0
I found the teamwork aspect to be beneficial to my learning.	7	Engagement	Teamwork	5	± 1.5	4	± 1.0	4	± 1.0	3	± 2.0
I found the teamwork aspect to hinder my learning.	8	Engagement	Teamwork	2	± 2.0	2	± 1.0	2	± 2.0	2	± 2.0
Because of the teamwork, I feel more confident in my own abilities.	9	Motivation	Teamwork	3	± 1.0	3	± 1.0	3	± 1.0	3	± 1.0
The teaching style during the lesson delivery was clear and encouraged peer interaction.	10	Perception		4	± 1.0	3	± 1.0	4	± 1.0	4	± 0.0
The teaching style increased my understanding of the material.	11	Engagement		4	± 1.0	3	± 0.0	3	± 1.0	4	± 2.0
The team activities were relevant to the learning goals.	12	Perception	Teamwork	5	± 1.0	3	± 1.0	4	± 2.0	4	± 2.0
It was easy to stay focused and engaged with the class during the lesson delivery.	13	Engagement		4	± 1.0	3	± 1.0	4	± 1.0	4	± 2.0
It was easy to stay focused and engaged with the class during the team activity and competition.	14	Engagement	Teamwork	4	± 1.0	3	± 1.0	4	± 1.0	4	± 2.0
Today's class was well-coordinated.	15	Perception		4	± 2.0	3.5	± 2.0	4	± 1.0	4	± 0.0
Today's class increased my interest in medicine and engineering.	16	Motivation		3	± 2.0	3	± 1.0	3	± 1.0	3	± 1.0
I would learn more in school if every class was taught this way.	17	Engagement	Perception	4	± 2.0	3	± 1.0	3	± 2.0	4	± 2.0
Today's class matched my expectations.	18	Perception		3	± 1.0	3	± 0.0	3	± 1.0	3	± 1.0
The activities helped me to better understand the material.	19	Engagement		4	± 1.5	3	± 1.0	3	± 1.0	4	± 1.0
Prior to attending this class, I was interested in a career in science, technology, engineering, or math.	20	Prior interest		3	± 2.0	3	± 2.0	2	± 1.0	3	± 1.0
I enjoyed the competition activity in today's class.	21	Engagement	Competition	4	± 2.0	3	± 1.0	3	± 1.0	3	± 2.0
I found that the competition increased my motivation to learn during class time.	22	Engagement	Competition	4	± 2.0	3	± 1.0	3	± 1.0	3	± 2.0
I found the competition to be beneficial to my learning.	23	Competition		3	± 2.0	3	± 1.0	3	± 1.0	3	± 1.0
I found the competition to hinder my learning.	24	Competition		3	± 2.0	3	± 1.0	2	± 1.0	3	± 2.0
I am satisfied with my performance in the competition.	25	Competition		4	± 2.0	2.5	± 1.3	3	± 1.0	4	± 2.0
Because of the competition, I feel more confident in my own abilities.	26	Competition		3	± 1.5	3	± 1.0	3	± 1.0	3	± 2.0
I was more engaged with the class because of the competition.	27	Engagement		4	± 1.0	3	± 1.0	3	± 1.0	4	± 2.0
I am interested in coming back for future sessions.	28	Engagement		3	± 2.0	3	± 0.5	3.5	± 2.0	4	± 1.0
Compared to the robotic arm activity, I was more engaged with the class and material.								3	± 2.0	3	± 2.0
Compared to the wound healing activity, I was more engaged with the class and material.						3	± 1.0	3	± 1.0	3	± 2.0
Compared to the C-section activity, I was more engaged with the class and material.										3	± 2.0

Table 2 (continued)

Statement	No.	Themes		Class 1		Class 2		Class 3		Class 4	
				Median	± IQR	Median	± IQR	Median	± IQR	Median	± IQR
My group works well as a team.		Teamwork	Engagement			3	± 2.0	3	± 1.0	3	± 2.0
Today's class improved my understanding of topic		Competition	Motivation					3	± 1.0	4	± 2.0

had likely never encountered topics such as surgical simulation or prosthetic design. Having said that, by the end of the program, most students reported increased interest and motivation to pursue related fields. The most effective sessions, that were the Wound Healing and Bioengineering Design classes, increased students' interest across the board. Responses to Question 2 ("Today's class increased my interest in the subject matter") averaged in the neutral to positive ranges for the Bioengineering Design and Wound Healing classes, the latter of which showed statistically significant differences in these responses as compared to the Bioprosthetic and Orthopedics and Women's Reproductive Health classes, respectively ($p = 0.011$ and 0.017). Similarly, responses to the statement "I feel more motivated to learn after today's class" were statistically different between the Wound Healing class and the two following days ($p<0.001$ and $p=0.029$, respectively), as well as between the Bioprosthetic and Orthopedic class as compared to the Bioengineering Design class ($p = 0.0057$), indicating significantly more positive results for the Wound Healing and Bioengineering Design classes.

These sessions included accessible materials, clear goals, and enough time to succeed. This aligns with prior studies showing that personal relevance, low entry-barriers, and immediate feedback are key drivers of interest in STEM [5, 6, 11, 30]. In contrast, Women's Reproductive Health's class had the lowest relative initial interest, although this difference was not statistically significant among class days, and its more abstract role-playing approach may have alienated some students despite its importance as a subject. This is in line with findings from K-12 STEM research where students are less engaged by content they perceive as emotionally distant or socially mismatched to their interests [30, 33].

Perception

Perceptions of teaching quality, lesson clarity, and instructional preparedness were generally high, particularly in the Wound Healing and Bioengineering Design classes. This instructional style of these sessions can fall under the authoritative one. This consists of combining clear structure with encouragement of autonomy and collaboration [49–51]. Students in these classes perceived the instructors as organized, the expectations as attainable, and the learning environment as supportive. In contrast, the Robotic Arm class received relatively lower perception scores, although this was not statistically significant, likely due to the mismatch between the complexity of the building task and the time available. While active learning is powerful, in the absence of clear, supportive structure, it can backfire as evidenced in this class, which leads to cognitive overload and student frustration [52, 53]. This reinforces prior research that warns against assuming that complex or time-consuming tasks inherently

Table 3 Alignment of workshop classes with learning outcomes

Class	Learning objectives achieved	Improvement needed
1. Wound Healing	High engagement	N/A
	High perception of teamwork	
	Increased interest in biomedical engineering	
	Clearly outlined task structure	
2. Bioprosthetics and Orthopedics	Exposure to engineering design and mechanical thinking	More structure or pre-scaffolding
	Problem-solving	More broken-down tasks
	Partial engagement with peers	How-to-do sheets with step-by-step approach instead of a video
		More time
3. Women's Reproductive Health	Moderate teamwork and coordination	Using a volunteer-based approach for the role distribution
4. Bioengineering Design	High creativity and student autonomy	Changing how the competition was assessed
	High perception of instructor support and engagement	Clarify students' expectations and evaluation process
	High teamwork and peer engagement	

result in better understanding [35, 53]. Additionally, the lack of pre-cut materials or templates may have created unproductive ambiguity in Class 2, that is a known risk factor for decreased perception of teaching quality in hands-on settings [33, 40]. This was evidenced by the significantly lower ratings to the statement "The activities helped me to better understand the material" as compared to the Wound Healing and Bioengineering Design days ($p<0.001$ and $p=0.0068$, respectively).

Engagement

High engagement in the classes on Wound Healing and Bioengineering Design can likely be attributed to two factors: tangible outcomes and task clarity. Suturing and prototype design yielded visible, achievable, and appropriate-for-the-time-assigned results. These types of "low-floor/high-ceiling" activities that are accessible to beginners yet rich in opportunity for creativity, have been shown to promote flow states and sustained attention in STEM learners [6, 54, 55]. On the other hand, the Bioprosthetics and Orthopedics class was characterized by significant disengagement. Students anecdotally expressed that the robotic arm challenge was unfeasible within the 75-min timeframe. This aligns with work by Kirschner et al. [56], who cautioned that poorly scaffolded discovery learning can lead to disillusionment when success is unlikely. Women's Reproductive Health class also showed lower relative engagement, though it is hypothesized for different reasons: anecdotal reports in student surveys may show that they didn't see the activity as personally or emotionally relevant, which merits future study. Prior research showed that if students don't see themselves in the class material, or if the learning feels performative rather than experiential, their engagement can suffer [57, 58].

Teamwork

Teamwork was generally perceived as beneficial, particularly in the Wound Healing class, where tasks were well-structured, and every student could contribute meaningfully as an individual within the team. This supports findings that successful group work depends not just on the presence of teams, but on the clarity of roles and alignment of goals [59, 60]. In contrast, the Bioprosthetics and Orthopedics class lacked the same scaffolding. Teams struggled to self-organize under time pressure, and the open-endedness nature of the challenge led to frustration. This is in line with past studies where the absence of structure in group tasks led to unequal participation and poor group cohesion [61, 62]. Having said that, even though Women's Reproductive Health class involved role-play, the task involved enough collaboration to generate procedural teamwork only without the satisfaction of a concrete deliverable. This was supported by the statistically significant differences found between the scoring of "I found the teamwork aspect to be beneficial to my learning" for the Wound Healing class as compared to the two following days ($p=0.014$ and $p=0.006$, respectively).

Competition

The competition element had a nuanced impact. When the task was structured, time-appropriate, and aligned with student abilities (as in Wound Healing and Bioengineering Design classes), competition appeared to increase focus and enjoyment. This was evidenced in particular as a result of the increased scoring for the "It was easy to stay focused and engaged with the class during the team activity and competition" statement for the Wound Healing class as compared to the two following days ($p=0.012$ and $p=0.136$, respectively). This is in line with literature on gamification and its role in enhancing learning [63–65]. Students saw the challenge as achievable and motivating. Having said that, in the Bioprosthetics and Orthopedics, the opposite occurred. Students felt overwhelmed by the complexity and time constraint, and none were able to complete the task. This situation illustrates what educational researchers designate as "unproductive frustration" [66, 67]. Unproductive frustration occurs when a task lacks sufficient scaffolding or seems unattainable that students disengage rather than push through [68–70]. The Bioengineering Design class's competition (peer judging) also led to dissatisfaction, with anecdotal reports showing students may have felt their work wasn't fairly evaluated. These outcomes stress that competition without clear rules or achievable benchmarks can exacerbate inequities in perception and motivation, particularly among students new to STEM [71, 72].

Limitations

We believe that changing the order of the workshop days or even grade level distribution of the student population may alter the results. This was not investigated in this study. While we are showing demographic information such as gender, grade level, and ethnicity, no subgroup analyses were performed. This was due to the exploratory/observational nature of this study. Future work with larger cohorts will be needed to understand and tell whether the outcomes have differential effects across demographic subgroups. Moreover, this study relied on self-reported perceptions of learning, motivation, teamwork, benefit of competition and engagement, rather than direct measures of student learning gains. No pre- or post-assessment was conducted to evaluate knowledge acquisition. Having said that, the findings in this study reflect students' perceived rather than demonstrated understanding. Additionally, the nature of the study was observational as in the intend was not to conduct a research project, instead, the results were compiled as they showed potential impact on future workshop design and development. Also, this study did not isolate the individual contributions of active learning and competition to student outcomes, as both elements were intentionally embedded in each workshop. Subsequently, the effects of these instructional strategies were discussed based on perceived patterns, not on experimental comparisons. Future studies with a more targeted design would better decouple their independent or combined impacts on engagement, motivation, and learning. Finally, an analysis of the developmental and age-appropriate nature of the activities was not performed.

Conclusion and Comments

The MTU TRIO 2024 STEM workshop demonstrated how experiential teamwork, and structured competition can significantly enhance student engagement and motivation for STEM education. The most effective learning activities were the ones that provided hands-on experiences, clear instructional guidance, and direct relevance to real-world applications. In contrast, activities that were overly complex or lacked structured teamwork were less effective in engaging students. The Wound Healing activity was the most effective for learning. It allowed students to practice a tangible, real-world skill under structured guidance. The hands-on nature and immediate feedback from the instructors helped students retain the knowledge more efficiently. Add to that, its practical application in medicine made it engaging and relevant. The C-section Simulation or the Women's Reproductive Health class was the best for fostering teamwork. This activity required students to collaborate closely, delegate tasks, and follow procedural steps to complete the simulated surgical procedure. The need for coordination, precision, and adherence to guidelines mirrored real-world medical teamwork. The Bioengineering Design activity kept students engaged throughout because it allowed creativity, problem-solving, and peer evaluation and provided at the same time structure. Unlike predetermined or predesigned tasks, this activity encouraged students to take ownership of their designs, in a way that ensured continuous involvement and accountability. The peer evaluation component further motivated students to stay engaged as they sought to present a compelling and innovative design.

Overall, the study underscores the importance of designing STEM outreach activities that balance structure, creativity, and teamwork in order to optimize student engagement, learning, and motivation. Future planned programs will ensure that activities align with students' interests, age appropriateness and provide sufficient support and time to complete complex tasks effectively.

Appendix

Appendix 1: Day 1 Questionnaire—Students Were Asked to Rate Their Responses on a Scale of 1 (Strongly Disagree) to 5 (Strongly Agree), in Addition to Providing Responses to Short-Answer Questions

Likert scale statements:

1. I had prior interest in the material taught today.
2. Today's class increased my interest in the subject matter.
3. The instructors appear to be well-prepared for today's class.
4. I feel more motivated to learn after today's class.
5. Today's class included a traditional lesson delivery.
6. Today's class included plenty of teamwork.
7. I found the teamwork aspect to be beneficial to my learning.
8. I found the teamwork aspect to hinder my learning.
9. Because of the teamwork, I feel more confident in my own abilities.
10. The teaching style during the lesson delivery was clear and encouraged peer interaction.
11. The teaching style increased my understanding of the material.
12. The team activities were relevant to the learning goals.
13. It was easy to stay focused and engaged with the class during the lesson delivery.
14. It was easy to stay focused and engaged with the class during the team activity and competition.
15. Today's class was well-coordinated.
16. Today's class increased my interest in medicine and engineering.
17. I would learn more in school if every class were taught this way.
19. Today's class matched my expectations.
20. The activities helped me to better understand the material.
21. Prior to attending this class, I was interested in a career in science, technology, engineering, or math.
22. I enjoyed the competition activity in today's class.
23. I found that the competition increased my motivation to learn during class time.
24. I found the competition to be beneficial to my learning.
25. I found the competition to hinder my learning.
26. I am satisfied with my performance in the competition.
27. Because of the competition, I feel more confident in my own abilities.
28. I was more engaged with the class because of the competition.
29. I am interested in coming back for future sessions.

Short-Answer Questions

30. What place did your team get in the competition? (Circle the appropriate section)

1st/2nd 3rd/4th/5th6th/7th/8th

31. What was the aspect of the class you enjoyed the most?
32. What was the aspect of the class you enjoyed the least?
33. How do you think this class can be improved?

Appendix 2: Day 2 Questionnaire—Students Were Asked to Rate Their Responses on a Scale of 1 (Strongly Disagree) to 5 (Strongly Agree), in Addition to Providing Responses to Short-Answer Questions

Likert scale statements:

1. I had prior interest in the material taught today.
2. Today's class increased my interest in the subject matter.
3. The instructors appear to be well-prepared for today's class.
4. I feel more motivated to learn after today's class.
5. Today's class included a traditional lesson delivery.
6. Today's class included plenty of teamwork.
7. I found the teamwork aspect to be beneficial to my learning.
8. I found the teamwork aspect to hurt my learning.
9. Because of the teamwork, I feel more confident in my own abilities.
10. The teaching style during the lesson delivery was clear and encouraged peer interaction.
11. The teaching style increased my understanding of the material.
12. The team activities were relevant to the learning goals.
13. It was easy to stay focused and engaged with the class during the lesson delivery.
14. It was easy to stay focused and engaged with the class during the team activity and competition.
15. Today's class was well-coordinated.

16. Today's class increased my interest in medicine and engineering.
17. I would learn more in school if every class was taught this way.
18. Today's class matched my expectations.
19. The activities helped me to better understand the material.
20. Prior to attending this class, I was interested in a career in science, technology, engineering, or math.
21. I enjoyed the competition activity in today's class.
22. I found that the competition increased my motivation to learn during class time.
23. I found the competition to be beneficial to my learning.
24. I found the competition to hurt my learning.
25. I am satisfied with my performance in the competition.
26. Because of the competition, I feel more confident in my own abilities.
27. I was more engaged with the class because of the competition.
28. I am interested in coming back for future sessions.
29. Compared to last week, I was more engaged with the class and material.
30. My group works well as a team.

Short-Answer Questions

1. What place did your team get in the competition? (Circle the appropriate section)

1st/2nd 3rd/4th/5th6th/7th/8th

2. What was the aspect of the class you enjoyed the most?
3. What was the aspect of the class you enjoyed the least?
4. How do you think this class can be improved?
5. Did you attend last week's class?YESNO

Appendix 3: Day 3 Questionnaire. Students were asked to rate their responses on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree), in addition to providing responses to short-answer questions.

Likert scale statements:

1. I had prior interest in the material taught today.
2. Today's class increased my interest in the subject matter.
3. The instructors appear to be well-prepared for today's class.
4. I feel more motivated to learn after today's class.
5. Today's class included a traditional lesson delivery.
6. Today's class included plenty of teamwork.
7. I found the teamwork aspect to be beneficial to my learning.
8. I found the teamwork aspect to hurt my learning.
9. Because of the teamwork, I feel more confident in my own abilities.
10. The teaching style during the lesson delivery was clear and encouraged peer interaction.
11. The teaching style increased my understanding of the material.
12. The team activities were relevant to the learning goals.
13. It was easy to stay focused and engaged with the class during the lesson delivery.
14. It was easy to stay focused and engaged with the class during the team activity and competition.
15. Today's class was well-coordinated.
16. Today's class increased my interest in medicine and engineering.
17. I would learn more in school if every class was taught this way.
18. Today's class matched my expectations.
19. The activities helped me to better understand the material.
20. Prior to attending this class, I was interested in a career in science, technology, engineering, or math.
21. I enjoyed the competition activity in today's class.
22. I found that the competition increased my motivation to learn during class time.
23. I found the competition to be beneficial to my learning.
24. I found the competition to hurt my learning.
25. I am satisfied with my performance in the competition.
26. Because of the competition, I feel more confident in my own abilities.
27. I was more engaged with the class because of the competition.
28. I am interested in coming back for future sessions.
29. Compared to the robotic arm activity, I was more engaged with the class and material.
30. Compared to the wound healing activity, I was more engaged with the class and material.
31. My group works well as a team.
32. Today's class improved my understanding of challenges in women's and rural health.

Short-Answer Questions

1. What place did your team get in the competition? (Circle the appropriate section)

1st/2nd 3rd/4th/5th6th/7th/8th

2. What was the aspect of the class you enjoyed the most?
3. What was the aspect of the class you enjoyed the least?
4. How do you think this class can be improved?

5. Did you attend last week's class (robotic arm)?YESNO
6. Did you attend the first class (wound healing)?YESNO

Appendix 4: Day 4 Questionnaire—Students Were Asked to Rate Their Responses on a Scale of 1 (Strongly Disagree) to 5 (Strongly Agree), in Addition to Providing Responses to Short-Answer Questions

Likert scale statements:

1. I had prior interest in the material taught today.
2. Today's class increased my interest in the subject matter.
3. The instructors appear to be well-prepared for today's class.
4. I feel more motivated to learn after today's class.
5. Today's class included a traditional lesson delivery.
6. Today's class included plenty of teamwork.
7. I found the teamwork aspect to be beneficial to my learning.
8. I found the teamwork aspect to hurt my learning.
9. Because of the teamwork, I feel more confident in my own abilities.
10. The teaching style during the lesson delivery was clear and encouraged peer interaction.
11. The teaching style increased my understanding of the material.
12. The team activities were relevant to the learning goals.
13. It was easy to stay focused and engaged with the class during the lesson delivery.
14. It was easy to stay focused and engaged with the class during the team activity and competition.
15. Today's class was well-coordinated.
16. Today's class increased my interest in medicine and engineering.
17. I would learn more in school if every class was taught this way.
18. Today's class matched my expectations.
19. The activities helped me to better understand the material.
20. Prior to attending this class, I was interested in a career in science, technology, engineering, or math.
21. I enjoyed the competition activity in today's class.
22. I found that the competition increased my motivation to learn during class time.
23. I found the competition to be beneficial to my learning.
24. I found the competition to hurt my learning.
25. I am satisfied with my performance in the competition.
26. Because of the competition, I feel more confident in my own abilities.
27. I was more engaged with the class because of the competition.
28. I am interested in coming back for future sessions.
29. Compared to the robotic arm activity, I was more engaged with the class and material.
30. Compared to the wound healing activity, I was more engaged with the class and material.
31. Compared to the C section activity, I was more engaged with the class and material.
32. My group works well as a team.
33. Today's class improved my understanding of product design.

Short-Answer Questions

1. What place did your team get in the competition? (Circle the appropriate section)

1st/2nd 3rd/4th5th/6th

2. What was the aspect of the class you enjoyed the most?
3 What was the aspect of the class you enjoyed the least?
4. How do you think this class can be improved?
5. Did you attend last week's class (C section)?YESNO
6. Did you attend the robotic arm class?YESNO
7. Did you attend the wound healing class?YESNO
8. Would you sign up again for a "biomedical engineering" workshop in the future? Or would you recommend this workshop to your peers?YES NO

Acknowledgements None.

Author Contributions The authors developed the workshop, ran it, collected and analyzed the data and wrote the manuscript.

Funding This research was partly funded by the National Science Foundation award number 2301649 and by the TRIO Upbound program at Michigan Technological University.

Data Availability All the data collected is presented in this manuscript whether within the main text or within the appendices.

Code Availability Not applicable.

Declarations

Conflict of interests None to report.

Ethical Approval This research was determined to be not human subject research.

Consent to Participate The TRIO program at Michigan Tech already obtained consent from the parents of the participants to be included in the classes and their evaluation questionnaires. Note that the questionnaires were submitted anonymously.

Consent for Publication Not applicable.

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