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Research Article

The Pull of Tissue Engineering: A STEM Outreach Program with a Modular Cyclic Stretch Device to Engage High School Students

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Abstract—In this paper we designed a STEM outreach program with a modular tissue engineering education tool (we refer to as "modular cyclic-stretch device") to engage high school students in STEM hands-on activities. Using simple machines such as gears and rotating cams, students were able to build a custom device to apply cyclic stretch to biomaterials. With the help of this hands-on activity, our outreach program helped students grasp tendon tissue biomechanics and understand the importance of applying biomechanical force to regenerate tendon tissue in a laboratory setting. The two-day outreach program comprised: 1. pre- and post-tests; 2. lectures; 3. laboratory sessions, including the microscopic examination of stained tissue sections and a hands-on group activity employing the modular cyclic-stretch device; and 4. homework. Assessment results suggest that our program supports improved student awareness and interest in tissue engineering as a future profession. The program elevated students' confidence in their ability to apply engineering principles to tasks such as building a modular cyclic-stretch device and measuring the mechanical properties of biological tissues. Building an educational bioreactor improved students' understanding of the dynamic nature of the human body and the importance of tissue engineering as an emerging discipline towards replacing or regenerating damaged organs. We propose that our modular device has great outreach potential to introduce tissue engineering concepts to high school and potentially college freshmen engineering students.

Keywords—Tissue engineering, Outreach education, Biomechanics, Hands-on learning.

INTRODUCTION

Tissue engineering (TE) is a broad, emerging field that aims to replace or repair damaged tissues in the human body. A common TE approach combines patient autologous cells with biomaterials to construct biologically relevant replacement scaffolds. These materials are subsequently prepared for implantation by subjecting them to appropriate chemical and mechanical signals using growth factors and bioreactors. Biomedical engineering (BME) contains tissue engineering as a subfield, and many BME curricula integrate TE coursework to prepare graduates to fill workforce needs and contribute to future regenerative therapies that could lead to entire organ replacement (e.g., a tendon, a liver). Such TE innovations would greatly benefit patients that currently must wait for matching organ donations. Introducing high school students to and engaging them with TE content is important, but can be challenging. TE requires complex laboratory equipment and procedures addressing biosafety, cells, and biomaterials development. Moreover, successful fabrication of mechanically active tissues often requires bioreactor usage prior to tissue implantation; bioreactors mimic the external forces the tissue would be exposed to *in vivo*.[1,2] Constructing bioreactors to accurately mimic biological conditions,

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however, is a long process, and it is difficult to implement such a learning experience through outreach programs given the time and resources required. Unfortunately, purely lecture-based TE training programs may not fully demonstrate the field's exciting potential for repairing or ultimately replacing damaged organs. For this reason, it would be ideal to involve students in a hands-on outreach activity to develop a bioreactor that mimics the *in vivo* environment of the desired tissue or organ to increase student learning and engagement.

Tendons are collagen-rich tissues that experience uniaxial cyclic loading. Tendons transmit muscle force to bones across a joint, thus enabling movement while providing joint stabilization. Tendons extend along the principal strain direction of the muscle and recoil longitudinally, a behavior reminiscent of springs.[3] Thus, tendons are could be exemplified as springs when relating their mechanical properties. Hooke's law governs the extension and recoil of springs under force; the extent of the strain is directly correlated with the magnitude of force that is applied. This ratio is encapsulated by the spring constant (k), which reflects the internal properties of the spring material.[4] Thus, the extent of a tendon's elongation is partially determined by the spring constant conferred by the tendon's biomaterial composition. This concept could be used as a simplified description of tendon mechanics when teaching junior students tendon biomechanics.

The use of bioreactors to create preconditioned TE tendon constructs allows application of varied mechanical regimens to tendons, enabling the correct alignment and organization of the cells and associated extracellular matrix (ECM). Combining scaffold architecture and correct mechanical conditioning is critical in correct TE strategy and, a multitude of bioreactor strategies have been tested for TE grafts. The first trials of pre-conditioned TE constructs used "clamp and stretch" bioreactors that either pre-strained or applied cyclic loading to the biomaterials designed for tendon regeneration. Subsequently, two-dimensional bioreactors used patterned surfaces (i.e., aligned nanofibrous scaffolds) to design TE constructs reminiscent of native tendon structure.[5] More recently, Banik et al. showed that a cyclic flexural stretch bioreactor with dynamic conditions increased tenocyte differentiation of mesenchymal stem cells compared to the results obtained with static conditions.[6]

Increasing student exposure to engineering before college has several advantages. First, students better understand the importance of utilizing science and mathematics to solve complex problems to improve human life. Second, engineering outreach programs increase student confidence and interest in engineering, which is often a challenge, especially for underrepresented groups. Third, engaging in complex tasks in a group setting enhances student communication and knowledge exchange. Finally, adopting an engineering approach to problem solving by first identifying the problem, making assumptions, listing the parameters and proposing solutions could translate to other areas of student life.[7] Furthermore, high school exposure to hands-on challenges could spark interest in current engineering problems and prime students to tackle medical and other bioengineering needs through future formal education.[8]

Several outreach programs have addressed special topics in tissue engineering, biomaterials development and biomechanics[9–11]; Knudson and Wallace.[12] Through an international program, Ahluwalia and collaborators implemented a BME design school for European and African students. Participants collaboratively built neonate devices to supply continuous airway pressure, provide warmth and offer phototheraphy to combat infant jaundice. Birol et. al and Harris & Brophy introduced BME subjects using different learning strategies, such as the "how people learn framework" or challenge-based learning.[10,11] Finally, Knudson and Wallace articulated how low-tech devices could aid in students learning of biomechanics concepts.[12] The aforementioned studies underscore the critical need to adopt hands-on activities to engage student learning. Program success is most enhanced when biomechanical concepts are illustrated through student hands-on learning activities. For instance, Klein et al.'s summer program successfully imparted biomechanical force concepts to high school students through hands-on activities using skin tissue.[13] In our outreach program, interactive lectures were followed by group hands-on activities and concluded with active learning questions. Active learning is an important teaching tool that cements knowledge and improve the effectiveness of outreach programs.[14] Active learning encourages students to synthesize the outreach material and embark on their own research journey.

In our study, we first designed and constructed a novel modular cyclic-stretch device for TE outreach activities. Next, we engaged high school students with tendon biomechanics and TE concepts through the outreach activity. We assessed the success of the program through pre- and post-test questionnaires evaluating participant tissue engineering knowledge and interest in engineering careers. After the outreach activity, students were given a short homework assignment to turn in to the course instructors as the active learning component of the program. We propose that students' knowledge of tissue engineering and their confidence in choosing engineering as a future profession increased after implementing our STEM outreach program.

MATERIALS AND METHODS

Modular Cyclic Stretch Device Design and Mechanical Construction

The first and third authors designed, constructed and implemented the use of the modular cyclic-stretch device to teach cyclic tendon stretch concepts and demonstrate how tendons stretch during normal locomotion while modeling a TE bioreactor in a laboratory setting. The device was designed to be portable, with all parts fitting into a 50 cm x 40 cm x 7 cm polyethylene container to accommodate different classroom settings. Due to safety considerations, all of the parts were chosen to operate under dry conditions and collectively weighed less than 5 kg. All components were selected for durability, affordability and ease of replacement from a commercial supplier (McMaster Carr, Chicago, IL, USA).

Tendons are subject to varying magnitudes of mechanical forces arising from their anatomical location and the properties of the connective tissue they are attached to. We used two simple machines to demonstrate cyclic stretch under different conditions using gears or a non-centrosymmetric cylindrical cam setup (Fig. 1a). Students could switch design elements to create their own bioreactors with stretching action based on gears or the cam for testing their biomaterials. The pieces of the modular cyclic-stretch device is shown in Fig. 1b. Mechanical pieces of the bioreactor comprised a clear, polyacrylic rectangular flat plate (20.4 cm x 13.2 cm) housing tracks positioned lengthwise for a sliding rail and served as a platform for placement of different gear combinations in 21 cylindrical pin-holes located between the tracks. The cam setup consisted of a clear polyacrylic rectangular hollow frame that encased the non-centrosymmetric cam hooked to a rotating motor shaft. The rotating shaft of the cam was placed to have a minimum distance of 1.5 cm and maximum distance of 4.7 cm from the rotating shaft. The moving part of the cam setup contained 5 equally separated type 316 stainless steel socket head screws to pull the biomaterials lengthwise and a stationary rectangular piece of polyacrylic plate to clamp the other side of the biomaterial (Fig. 1c). Three different types of 48-pitch nylon gears (42, 60 and 80 teeth; 2.2 cm, 3.1 cm and 4.2 cm pitch diameters) with a 0.6 cm bore hole size were purchased along with 0.6 cm diameter Teflon rods were provided secure the gears inside the bore holes in the base plate (Fig. 1d).

Tissue Engineering Outreach Program

We designed a two-day STEM outreach program featuring a modular cyclic-stretch device for high school students. We consulted the Tokat Primary and Secondary Education Council to gather detailed information that was taken into account by outreach program's design. After program approval by the Tokat Primary and Secondary Education Council and the Tokat Gaziosmanpasa University Institutional Review Board (IRB), school officials randomly selected 10 junior high school students (5 male and 5 female) as participants. All of the students were from the science major in Tokat Gaziosmanpasa High School. The academic performance of the selected students was within their class' average. The sample size was limited to 10 students working in two teams for two reasons. First, participating students had not had prior laboratory experience. Thus, a small number of students were included to ensure adequate laboratory supervision and safety by a limited number of volunteer undergraduate assistants. Second, we had two modular kits and we aimed to maximize each student's access to the device components. Each team was composed of both male and female students. All students participated voluntarily, along with a science teacher and the high school vice principle. The program was held over a weekend when the students were on their 2018 winter break from classes. The detailed schedule of the outreach program is given in Table S1. Program effectiveness was evaluated through pre- and post-instructional surveys and a homework exercise. The focused learning objectives of this study were as follows:

- Students consider engineering to be an interesting future profession;
- Student engage in activities requiring engineering skills;
- Students understand spring-like properties of tendons and can calculate a tendon spring coefficient with given parameters;
- Students know that biomaterials can be utilized to regenerate damaged tissues; and
- Students understand the function of tendons in our bodies and can give other examples of elastic tissues.

FIRST DAY OF OUTREACH PROGRAM

Following administration of pre-instructional surveys, an instructional lecture was given containing information on engineering, science and tissue engineering concepts. The afternoon session began with a

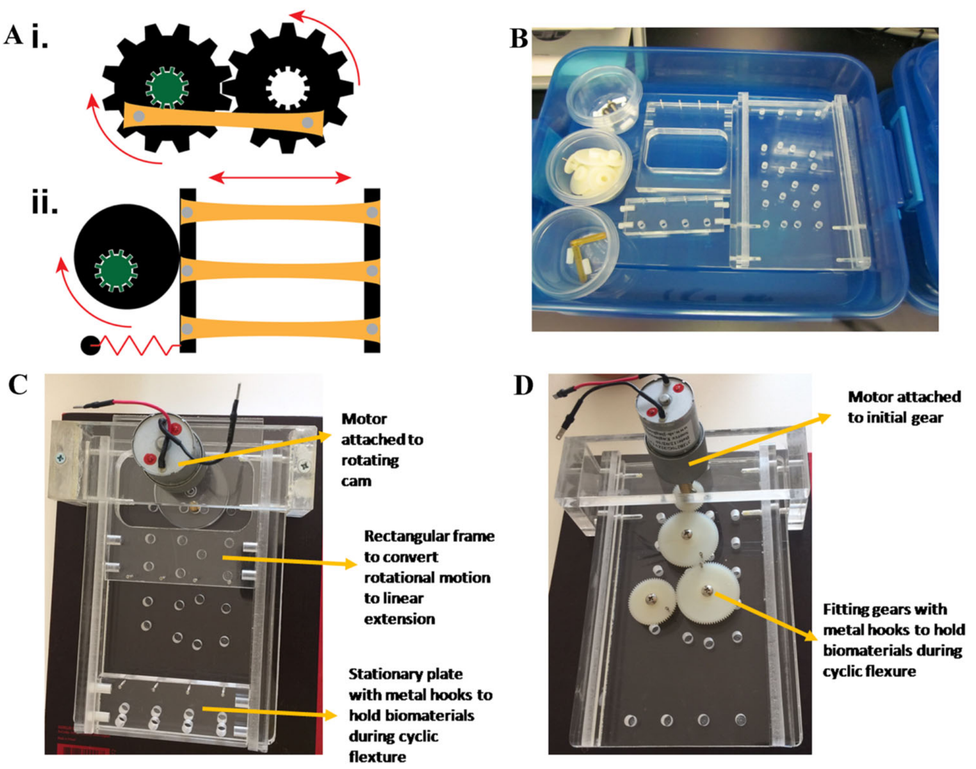


FIGURE 1. Step-by-step design and development scheme of the STEM education bioreactor. (a). Gears (i) and a sliding cam (ii) were used as devices to stretch the biomaterials. (b). STEM Tendon TE Bioreactor Laboratory Kit. Assembled rotational cam (c) and gear (d) assembly setup with biomaterials placed onto the holders for cyclic flexure testing.

laboratory safety unit followed by an instructional lecture on the anatomy and physiology of tendons. After, students were escorted to the laboratory by the undergraduate assistants, provided with personal protective equipment (PPE) and divided into two groups. After a hands-on demonstration, students used light microscopes to view Hematoxyllin & Eosin- (H&E-) stained tissue sections and observe the microscopic architecture of bone, tendon, muscle and nerve tissues.

SECOND DAY OF OUTREACH PROGRAM

The second day started with an instructional lecture on bioreactors used for tissue engineering studies, particular those focused on tendons. The participants discussed the importance of applying appropriate mechanical forces when regenerating tendons. For instance, a rotator cuff tendon has to bear tensions in circular motions, but Achilles tendons usually bear tensions resulting from linear motions. After the instructional session, students donned PPE and were escorted to the laboratory to build the cyclic stretch device for tendon TE. Each group was provided with a Bioreactor Laboratory Kit containing both cam and gear setup, including a DC power supply and polyester circular elastomeric biomaterials. Each group received a complete kit containing bioreactor parts and a rotational shaft motor (Jingkong Source Engineering, China). In addition to the bioreactor kit, there was a DC power supply, pieces of polyester circular elastomeric biomaterials supplied to each group of students. To encourage student creativity, the instructors reviewed kit contents without revealing full instructions for reactor assembly. Each group was instructed to work as a team before they assembled the bioreactor pieces. The instructors and volunteer undergraduate students assisted in answering participant questions as they arose. Once the teams assembled the pieces to form either the gear setup or cam setup (Fig. 1c and d), the biomaterials were placed in the holders, and the participants measured related length and stretched the biomaterials. The participants recorded observations in their notebooks. Once all the measurements were completed, a short question and answer session was held before the closure of the Tendon Bioreactor lab session.

Data Collection Instruments

Program effectiveness was evaluated using three instruments. First, we applied the Engineering Career Interest Survey (ECIS)[15] translated into Turkish by

Unlu et al.[16] The ECIS is one of the four subdimensions evaluated by the Science Technology Engineering and Mathematics (STEM) Career Interest Survey. This survey was developed to measure the effects of strategies intended to promote the awareness of, interest in and intent to pursue STEM careers by students. The ECIS includes 10 items with a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Participants marked a choice for each item. Table S2 presents select sample items from the ECIS.

Second, we administered the Tissue Engineering Knowledge Test (TEKT), developed by the first and fourth authors, who are active TE researchers. This survey was developed to measure students' knowledge of basic concepts related to TE. The TEKT includes six open-ended questions (Table S4).

Third, we measured the participants' reactions to the outreach program using the Educational Program Evaluation Form (EPEF).[17] This form asked participants to use a Likert-type scale (1 [disagree completely] to 5 [agree completely]) to evaluate the outreach program on organization, quality of instruction, materials, the environment and the process. Table S3 shows representative items from each aspect of the EPEF.

The ECIS and the TEKT were administered before and after the instruction. The EPEF was applied after the instruction. Students answered all the questions in pre- and post-test surveys during the times designated for surveys. Before each survey, the second author introduced and explained the purpose of the instrument to the students. Written instructions were also provided with survey questions.

One week after the program, participants were contacted and asked to complete a small homework assignment consisting of two parts. The first portion asked participants to use their laboratory measurements to calculate the spring constants of the biomaterials and compare each to the spring constant of native tendons. Based on Hooke's Law, the displacement or size of the deformation of an object is directly proportional to the force applied to it. For each elastic material, the force required per unit displacement describes its elastic property as given by its spring constant $k = \Delta F/\Delta x$ where ΔF is the change in force (Newton) applied to a spring and Δx is the change in length (m) in response to the force applied to the spring. In the second part of the homework assignment, participants were asked to research other tissues that can extend like tendons and behave like springs, and then draw their anatomical structure. Participants turned in their completed homework at school one month after the assignment was issued.

Data Analysis

Data were analyzed using SPSS 22.0 (Statistical Package for Social Sciences, Chicago, IL). The significance level was set to 0.05. In order to evaluate the effect of the outreach program on students' interest in engineering-related careers and knowledge of basic TE concepts, the Wilcoxon signed-rank test was used. This test determines the difference between repeated measurements of two related samples, especially for small sample sizes.[18] Also, descriptive statistics, such as mean scores and standard deviations were used to interpret the data.

RESULTS AND DISCUSSION

In this study, we designed and implemented a two-day outreach program with a lecture-based component and a hands-on learning activity for 10 junior high school students. We held lectures in college classrooms at Gaziosmanpasa University and used Bioengineering Department laboratory space for laboratory components. Both spaces were prepared for the education program for safety. Four Bioengineering undergraduate students volunteered to help supervise the high school students. Program lectures introduced and explored TE concepts. Participants used our modular kit to explore the application of Hooke's Law to elastic materials to model properties of tendon tissue. Participants worked in mixed teams of females and males. Each team deployed two separate device setups of matching gears and rotating cams and observed the resulting deformation of biomaterials. Topical learning was reinforced through homework. Program aims and questions were evaluated with three instruments and student homework.

The program aimed to increase participants' fundamental TE knowledge and particularly to address the important role of mechanical engineering in generating active tissues such as tendons. The program also aimed to increase participants' interest in engineering as a career option.

In the study, the following research questions were investigated:

1. Did the outreach program increase participants' knowledge of basic TE concepts?
2. How did the outreach program affect participants' engineering career interest?
3. What were participant views on the implementation of the outreach program?

Students' Knowledge of Basic TE Concepts

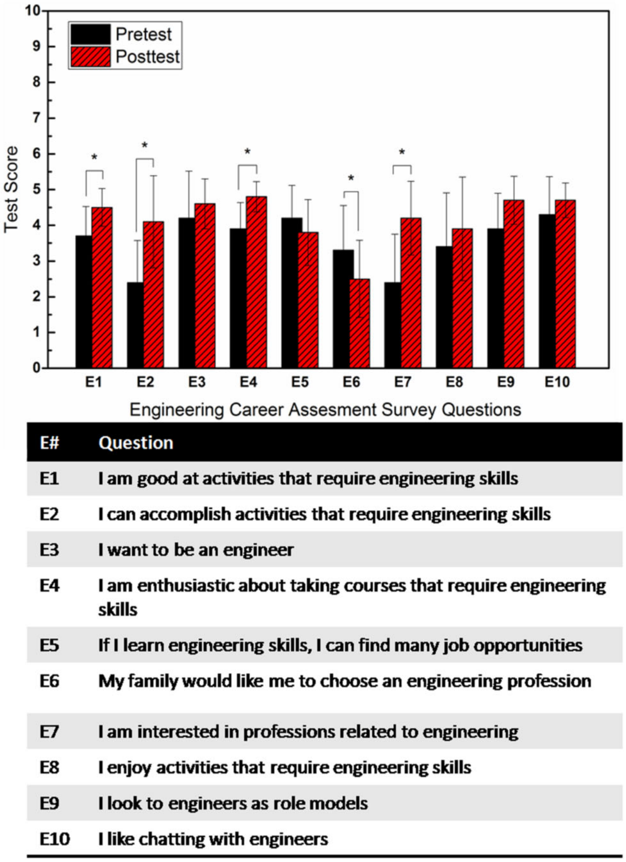
We measured changes in the participants' TE knowledge levels using the TEKT's six open-ended questions administered before and after the program. Question responses were evaluated as correct, partially correct or incorrect, and pre- and post-test frequencies are presented in Fig. 2.

Participants' mean correct score rose from 2.5 out of 12 (standard deviation, s.d. = 1.43) on the pre-test to 7.6 (s.d. = 2.16) on their post-test; a Wilcoxon signed-rank test comparing students' repeated measurements showed a significant increase in student TEKT scores ($z = -2.81$, $p < 0.05$).

Notably, the number of participants that correctly answered each TEKT question increased for each post-test question, excepting responses for Question 6. Question 6 asked students to calculate the spring constant of a soccer player's Achilles tendon using Hooke's Law in a timed setting. However, the number of participants who answered Question 6 partially correct increased from 5 to 7 students at the conclusion of the study. Notably, all students correctly solved a similar calculation as part of their homework assignment (Question 1) after the program (Table 1). Students additionally investigated the function of a chosen body tissue other than tendons through cyclic stretch (Question 2). The homework assignment aimed to strengthen the concepts introduced in the education program and to facilitate individuals' research skills.

Students' Engineering Career Interests

We applied the ECIS to measure the outreach program's effect on participant interest in engineering careers. Responses were recorded on a 5-point Likert-type scale for each of the instrument's 10 items (Table S2), and pre- and post-test descriptive statistics for each item are presented in Table S5. Participants' overall scores increased from a pre-test mean score of 35.70 out of 50 (s.d. = 4.85) to a post-test mean score of 41.80 (s.d. = 4.78) . A Wilcoxon signed-rank test indicated a significant positive increase in post-test ECIS scores ($z = -2.70$, $p < 0.05$). Higher post-test scores show an overall positive impact of the outreach program on participant interests in and perceptions of engineering careers.



E#	Question
E1	I am good at activities that require engineering skills
E2	I can accomplish activities that require engineering skills
E3	I want to be an engineer
E4	I am enthusiastic about taking courses that require engineering skills
E5	If I learn engineering skills, I can find many job opportunities
E6	My family would like me to choose an engineering profession
E7	I am interested in professions related to engineering
E8	I enjoy activities that require engineering skills
E9	I look to engineers as role models
E10	I like chatting with engineers

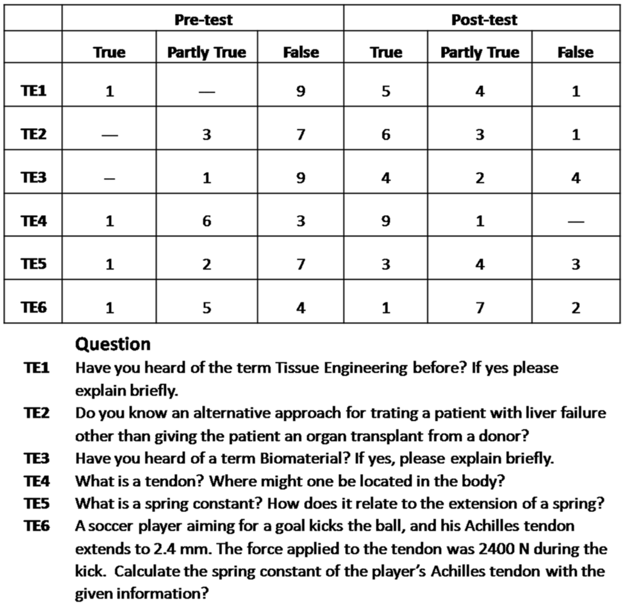
FIGURE 2. Summary of results from the Engineering Career Interest Survey (ECIS) questions. Statistical significance was determined based on the Wilcoxon signed-ranks test and * represents a p<0.05.

TABLE 1. Summary of Student Homework Assessments.

Student	Question 1	Question 2
1	Answered correctly and made correct comparisons with tendon	Chose ligaments and explained their working principles
2		Chose heart muscle tissue and drew the 3D macroscopic architecture of the tissue
3		Chose elastic fibers in the skin and explained how their microscopic structure supports cyclic stretch
4		Chose skeletal muscle tissue as the elastic tissue
5		Also chose elastic fibers and explained the working principles in detail and the extracellular matrix components leading to the cyclic stretch behavior
6		Chose a specific tendon type (flexor tendons) and draw the anatomical structure
7		Also chose elastic fibers, briefly explained their function and drew their microscopic structure
8		Also chose ligaments and drew the anatomical structure of the tissue
9		Also chose ligaments and drew their simplified anatomical structure, and focused more on how their spring-like function serves the body
10		Chose diaphragm as an elastic tissue with cyclic stretch. Drew anatomical drawings with surrounding organs and explained the function

Individual ECIS questions tracked students' interest and self-confidence in as well as perception of engineering and related careers. The number of participants responding positively to each ECIS question increased on the post-test, excepting those for questions E5 and E6, where more participants responded negatively on the post-test (Fig. 3). Pre- and post-test scores for questions E1, E2, E4, E6 and E7 differed significantly.

Demonstrating the strength of our outreach program, students' enthusiasm for coursework requiring engineering skills (E4) and their interests in engineering-related professions increased significantly (E7). Additionally, students' self-confidence in their ability to perform engineering tasks increased (E1 and E2). Only one student expressed that while the outreach program helped him understand engineering- and medicine-related professions, he found these career options less appealing at the conclusion of the program.



	Pre-test			Post-test		
	True	Partly True	False	True	Partly True	False
TE1	1	—	9	5	4	1
TE2	—	3	7	6	3	1
TE3	–	1	9	4	2	4
TE4	1	6	3	9	1	—
TE5	1	2	7	3	4	3
TE6	1	5	4	1	7	2

	Question
TE1	Have you heard of the term Tissue Engineering before? If yes please explain briefly.
TE2	Do you know an alternative approach for trating a patient with liver failure other than giving the patient an organ transplant from a donor?
TE3	Have you heard of a term Biomaterial? If yes, please explain briefly.
TE4	What is a tendon? Where might one be located in the body?
TE5	What is a spring constant? How does it relate to the extension of a spring?
TE6	A soccer player aiming for a goal kicks the ball, and his Achilles tendon extends to 2.4 mm. The force applied to the tendon was 2400 N during the kick. Calculate the spring constant of the player's Achilles tendon with the given information?

FIGURE 3. Summary of results from the Tissue Engineering Knowledge Test (TEKT) questions. Statistical significance was determined based on the Wilcoxon signed-ranks test and * represents a $p<0.05$.

Interestingly, students' perception about their family's approval on choosing engineering career decreased at the conclusion of the outreach program. This decline may be partly attributed to fears associated with finding jobs after graduation due to popularity of medicine and business-related professions in Turkey.

Importantly, our outreach program significantly improved female participants' interest in engineering professions (E7) (Fig. 4). Males also exhibited a positive increase in engineering careers, but the difference was not significant. These results are supported by prior studies. Interest in pursuing engineering careers is considered one of the benefits of engineering education for K-12 students.[19] However, student surveys indicate that male students generally show interest in engineering-related careers more often than do female students.[20–22] Once suitable learning experiences are implemented, female students especially show increased interest in engineering-related careers,[23,24] as was exhibited in this study.

Notably, our general observations from the laboratory session corroborated the changes between the pre- and post-test scores for female participants. Almost all students were interested in the laboratory

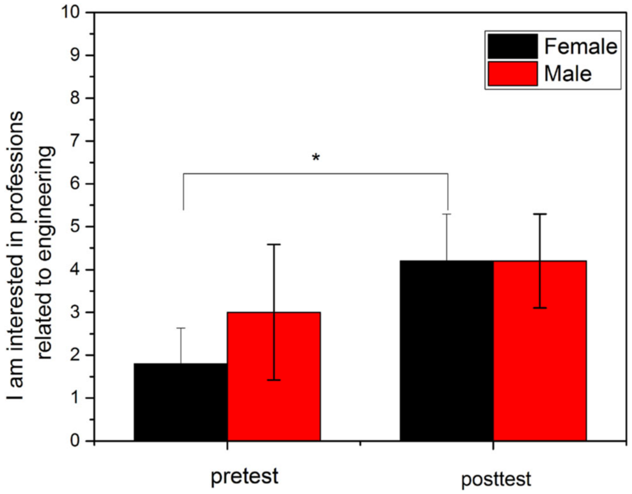


FIGURE 4. Gender-based comparison of student interest in engineering related careers. Data is represented as mean ± s.d. Statistically significant score differences were determined with Wilcoxon signed-ranks test and * represents a p<0.05.

TABLE 2. Descriptive statistics of EPEF subdimensions.

Dimension	Number of participants	Mean score (x̄)	Standard deviation (s.d.)
Organization	10	4.54	0.68
Trainer	10	4.80	0.56
Materials	10	4.47	0.80
Environment	10	4.64	0.52
Process	10	4.52	0.62

sessions. Female students were initially reluctant to handle the device pieces and the power supply. Male students were initially more inclined to handle the pieces more confidently than female students. However, after the instructors delivered a brief exercise introduction that explained the role of each piece and safety precautions, female students easily manipulated kit components, trying multiple gear combinations to apply different magnitudes of stretch to the biomaterials.

Taken together, the results indicate that our outreach activity for precollege students could help participants discover new engineering career interests and opportunities before selecting college majors. Additionally, this program can help address the gender gap in engineering fields by engaging female students in engineering activities. We believe further interactions with engineering faculty could positively affect female student engagement.

Students' Perceptions of the Education Program

Participants' views of the outreach program were determined through the EPEF, and descriptive statistics of the EPEF subdimensions are presented in Table 2. The table shows that subdimension averages ranged from 4.47 to 4.80 out of 5. The trainer and process subdimensions received the highest and lowest scores, respectively. However, the overall high scores (>4) in all dimensions indicate that participants were satisfied with the outreach experience and that the program was a success.

CONCLUSION

Tissue Engineering is an emerging discipline that offers the bright promise of generating tissues and organs *de novo*, replacing the need for organ donations. Bioreactors are essential components of successful TE strategy when targeting organs that operate under mechanical loads such as tendons. Teaching high school students with limited TE knowledge about the important role of bioreactors requires engagement through both theoretical lectures and hands-on learning activities. In this study, we employed a do-it-yourself cyclic stretch device as part of a TE outreach program to introduce tendon biomechanics and regeneration strategies to junior high-school students. Results indicate that our two-day educational program successfully introduced TE concepts, including fundamental tendon biomechanics to students and increased their interest in choosing engineering as a future career. Using our kit's modular components, students constructed either a cam- or gear-operated cyclic stretch device; applied longitudinal stretch to supplied biomaterial samples; and calculated the spring constants of biomaterials. Students further compared the laboratory biomaterial spring constants to the spring constants of actual tendons using published literature through a homework assignment. This program is a novel outreach model to engage students in tendon biomechanics and TE using a modular cyclic stretch device. We believe that our hands-on outreach program offers future potential to encouraging high school students to explore tissue engineering as future career.

SUPPLEMENTARY INFORMATION

The online version of this article contains supplementary material available (https://doi.org/10.1007/s43683-021-00053-0).

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REFERENCES

[1] Garceau LR, Ebben WP, Knudson DV. Teaching practices of the undergraduate introductory biomechanics faculty: a North American survey. Sports Biomech. 2012;11:542–58.

[2] Hsieh C, Smith JD, Bohne M, Knudson D. Factors related to students' learning of biomechanics concepts. J Coll Sci Teach. 2012;41:82–9.

[3] Wang T, Chen P, Zheng M, Wang A, Lloyd D, Leys T, Zheng Q, Zheng MH. In vitro loading models for tendon mechanobiology. J Orthop Res. 2018;36:566–75.

[4] Giuliodori MJ, Lujan HL, Briggs WS, Palani G, DiCarlo SE. Hooke's law: applications of a recurring principle. Adv Physiol Educ. 2009;33:293–6.

[5] Dyment NA, Barrett JG, Awad HA, Bautista CA, Banes AJ, Butler DL. A brief history of tendon and ligament bioreactors: Impact and future prospects. J Orthop Res. 2020;38:2318–30.

[6] Banik BL, Brown JL. 3D-printed bioreactor enhances potential for tendon tissue engineering. Regener Eng Transl Med. 2020;6(4):419–28.

[7] Svihla V, Petrosino AJ, Diller KR. Learning to design: authenticity, negotiation, and innovation. Int J Eng Educ. 2012;28:782.

[8] Marshall JA, Berland LK. Developing a vision of pre-college engineering education. J Pre-Coll Eng Educ Res. 2012;2(2):5.

[9] Ahluwalia A, Carmelo De Maria J, Madete AD, Lantada PN, Makobore AR, Di Pietro L, Mridha M, Munoz-Guijosa JM, Chacón Tanarro E. Biomedical engineering project based learning: Euro-African design school focused on medical devices. Int J Eng Educ. 2018;34:1709–22.

[10] Birol G, Liu S, David Smith H, Hirsch P. Educational modules in tissue engineering based on the "how people learn" framework. Biosci Educ. 2006;7:1–13.

[11] Harris TR, Brophy SP. Challenge-based instruction in biomedical engineering: a scalable method to increase the efficiency and effectiveness of teaching and learning in biomedical engineering. Med Eng Phys. 2005;27:617–24.

[12] Knudson D, Wallace B. Student perceptions of low-tech active learning and mastery of introductory biomechanics concepts. Sports Biomechanics; 2019.

[13] Klein SS. Using a study of skin to teach stress and strain in high school physics, anatomy and physiology, and engineering. In: Proceedings of the 9th international conference on engineering education; 2006.

[14] Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci USA. 2014;111:8410–5.

[15] Kier MW, Blanchard MR, Osborne JW, Albert JL. The development of the STEM career interest survey (STEM-CIS). Res Sci Educ. 2014;44:461–81.

[16] Unlu ZK, Dököe İ, Ünlü V. Adaptation of the science, technology, engineering, and mathematics career interest survey (STEM-CIS) into Turkish. Eurasian J Educ Res. 2016;16(63):21–36. https://doi.org/10.14689/ejer.2016.63.2.

[17] Ilhan T. Yilmaz F., Kilicer K., Senocak E. The professional and social development of prison staff." In. Erasmus Program of European Commission: Tokat; 2018.

[18] Kraska-Miller M. Nonparametric statistics for social and behavioral sciences. Boca Raton: CRC Press; 2013.

[19] Wright GA. Engineering attitudes: an investigation of the effect of literature on student attitudes toward engineering. Int J Technol Des Educ. 2018;28(3):653–65. https://doi.org/10.1007/s10798-017-9417-0.

[20] Ito TA, McPherson E. Factors influencing high school students' interest in pSTEM. Front Psychol. 2018;9:1535.

[21] Jung E, Kim JYE. Women in engineering: almost no gap at university but a long way to go for sustaining careers. Sustainability. 2020;12:8299.

[22] Pearson W, Miller JD. Pathways to an engineering career. Peabody J Educ. 2012;87:46–61.

[23] Amelink CT, Creamer EG. Gender differences in elements of the undergraduate experience that influence satisfaction with the engineering major and the intent to pursue engineering as a career. J Eng Educ. 2010;99:81–92.

[24] Reynolds B, Mehalik MM, Lovell MR, Schunn CD. Increasing student awareness of and interest in engineering as a career option through design-based learning. Int J Eng Educ. 2009;25:788.