# Introducing High School Students to Biomedical Engineering through Summer Camps

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## Abstract

Summer camps provide many high school students their first opportunity to learn about various disciplines in the engineering profession. A week-long summer camp in Biomedical Engineering (BME) was used to introduce students to many of the topics that make up this discipline, and to engage them in learning through hands-on activities, discussions and lab tours. The BME topic areas that were covered in this summer camp were biomechanics, bioMEMS, medical imaging and medical sensors. Of the students that responded in the exit surveys, 71% of student rated the summer camp as good and 57% said that they will probably recommend the camp to others. Summer camps and outreach days for high school students can be an effective means for introducing young people to BME through tailored activities that used the resources available at the host academic institution.


## Introduction

### Biomedical Engineering

Biomedical Engineering (BME) is a relatively recent addition at many traditional engineering schools with an increasing number of academic institutions now offering a Bachelors of Science (BS) degree in BME. The field of BME merges engineering disciplines such as mechanical, chemical, and electrical engineering with biology-based disciplines of life sciences and medicine.  This merger was prompted by the need to improve procedures such as diagnostics, therapeutics, noninvasive surgical techniques, patient rehabilitation and quantitative analyses for biological problems [1]. The multidisciplinary nature of the field means that students in BME need to develop a broad based set of skills and knowledge. They need the modeling and quantitative skills of traditional engineers, but they also need the systems understanding representative of a more biological approach.

The broad range of topics covered in BME also make it difficult to present this discipline with the similar cohesive image as that of other engineering fields. High school students may have varied perceptions about what a BS in BME entails. This includes an unclear understanding of the BME concentrations, the type of courses taken by BME undergraduates and the future jobs filled by Biomedical Engineers. The heavy emphasis on scientific research and a lack of understanding of the subtopics within BME also increases the confusion and may  drive potential students away from an otherwise, exciting and *in-demand*, field of study.

## Summer Camps

Summer camps are offered by many academic institutions as a means to introduce the high school students to areas and fields of study that they might be interested in. Universities and programs also use these opportunities to showcase their academic institution and attract students towards enrollment in the program [2, 3]. Many programs, especially the ones with week-long resident aspect built into the camp, also allow the students to explore the general college lifestyle and campus activities. Some programs may even hand out grades that can be used as transferable credit. Other programs may focus on increasing female or minority participation in engineering. Regardless of the specific circumstances, summer engineering program can be a great way to introduce engineering fields and expand student understanding of the college experiences.

Setting up a summer camp curriculum from scratch may be a daunting task for BME faculty members. Therefore, it is important to use the existing subject matter and facilities that are available at the institution in order to reduce some of the burden and to ensure that the summer camp participants are getting high quality introduction. Instructors can modify many of the established teaching approaches and learning outcomes that are used for first year engineering courses to also teach summer camps [4, 5]. They can readily use engagement tools such as internet resources and simulations, but may need to carefully screen through many offerings to find the most suitable techniques. Universities focused on engineering pedagogy can utilize teaching methodologies to increase engagement during summer camps and focus activities to highlight key areas of education and research.

## Summer Camp in Biomedical Engineering

Lawrence Technological University (LTU) is a regional, private technical university that emphasizes engineering pedagogy. The university offers many outreach activities where high school students have an opportunity to learn and experience different engineering degrees including summer camps. The goal of the summer camp in BME is to give the participants an opportunity to explore the roles of biomedical engineers in ‘designing procedures and equipment that assist in the prevention, diagnosis and treatment of disease and injury’. The participants have varied backgrounds and motivations for attending the camp . As such, the technical information must be inclusive and presented in a manner that is both engaging and informative.

## Overview

The camp enrollment was capped at 16 students. The overall strategy for the camp was to include a variety of learning modalities and include videos, demonstrations, simulations, hand-on activities and active learning techniques to increase student engagement [6, 7]. An oral survey at the start of the Day 1 was indicative of the motivation and reason for interest in the camp. Most students cited the desire to learn more about BME as the primary reason for joining the camp. Many had little to no understanding of studying BME for an undergraduate degree and had been prompted to consider it by family members due to the perceived employment opportunities.

Prosthetics were a popular area of interest among students. The camp was taught by three Staff/Faculty members. Two days were dedicated for biomechanics and orthopedics related activities, two for biosensing and medical device applications and one for biomedical imaging including a trip to a radiology department at St. John Providence hospital, in Southfield, Michigan. Table 1 shows all the topics and activities during the summer camp.

| Day/ Time | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| **Theme** | **Introduction** | **Biomechanics** | **Biosensors** | **Imaging** | **MEMS** |
| **9 am** | **Activity:** Group Ice breaker | **Presentation:** Anthropometry **Activity:** Body segment measurement | **Presentation:** Biosensor measurements **Activity:** ECG and effect of exercise | **Presentation:** Medical imaging modalities **Demonstration:** MIMICS software | **Presentation:** MEMS techniques for miniaturization **Demonstration:** MEMS fabrication |
| **10 am** | **Presentation:** Motion capture **Demonstration:** Kinect game Nike Fit | **Presentation:** Video analysis **Demonstration:** Kinovia 2D analysis software | **Presentation:** Miniaturization of medical devices **Demonstration:** Try a handheld ECG monitor | **Activity:** MIMICS surgical simulation | **Activity:** PDMS microfluidics device fabrication and testing |
| **11 am** | **Activity:** Kinect and Wii Balance Board | **Activity:** Joints range of motion measurement | **Presentation:** Temperature sensors **Activity:** Build and test a temperature sensor | **Presentation:** Microscopy and ESEM **Demonstration:** ESEM with microtester | **Presentation:** Alternative fabrication methods **Activity:** Design a microfluidic device |
| **Lunch** | | | | | |
| **1 pm** | **Presentation:** Orthopedic surgery **Simulation:** Edheads.com total knee replacement | **Presentation:** 3D motion analysis **Demonstration:** Vicon motion capture system | **Presentation:** Blood pressure sensors **Activity:** Name that device | **Tour:** Radiology Department | **Activity:** Take apart pregnancy test |
| **2 pm** | **Activity:** Sawbones ACL reconstruction | **Activity:** 3D human movement analysis | **Presentation:** EEG and brain/ computer interface **Activity:** EEG game contest | **Tour:** Orthopedic Research Lab | **Activity:** Print CAD design and test |
| **3 pm** | **Presentation:** Surgical techniques **Activity:** Endoscopy and suturing skills | **Presentation:** Foot center of pressure **Activity:** Foot type measurement | **Presentation:** Stimulation **Discussion:** Detection vs. Intervention | **Tour:** Surgical Simulation Lab | **Activity:** Poster session |

Table 1: The activities and topics presented have been broken down by each day. The table also summarizes the time allocated for each activity.

The first day began with an icebreaker activity. Students were asked to rank medical devices in the chronological order of invention, first individually, then in teams of two and four. This not only allowed them to get to know each other but also helped them realize how group knowledge exceeds the knowledge of an individual. These active collaborative learning activities are an effective way to start group discussions and allowed the students in the summer camp to immediately engage with their peers and instructor. Since summer camps run for a short time, such activities are very beneficial to pave the way for presentation and open discussion of in-depth topics.

Biomechanics and Motion Capture

Rehabilitation of athletes as well as use of modern day prosthetics is a popular entry point into BME for many high school students. The technology used to restore mobility to amputees and the advancements in biorobotics makes this area of study more accessible and relevant to new students. It is also easier to communicate some of the future job opportunities where BME are improving outcomes for people. The Experimental Biomechanics Lab is equipped with a Vicon motion capture system and the topic was initially presented through the historical use of such systems in gait analysis and automobile accident research. One student was prepared for 3D motion analysis by attaching 39 retro-reflective markers to the body segments defined by the Vicon “Plug-in Gait” biomechanical model (Fig. 1). After calibration, a number of motion trials were recorded during various human movement activities, such as walking and jumping.

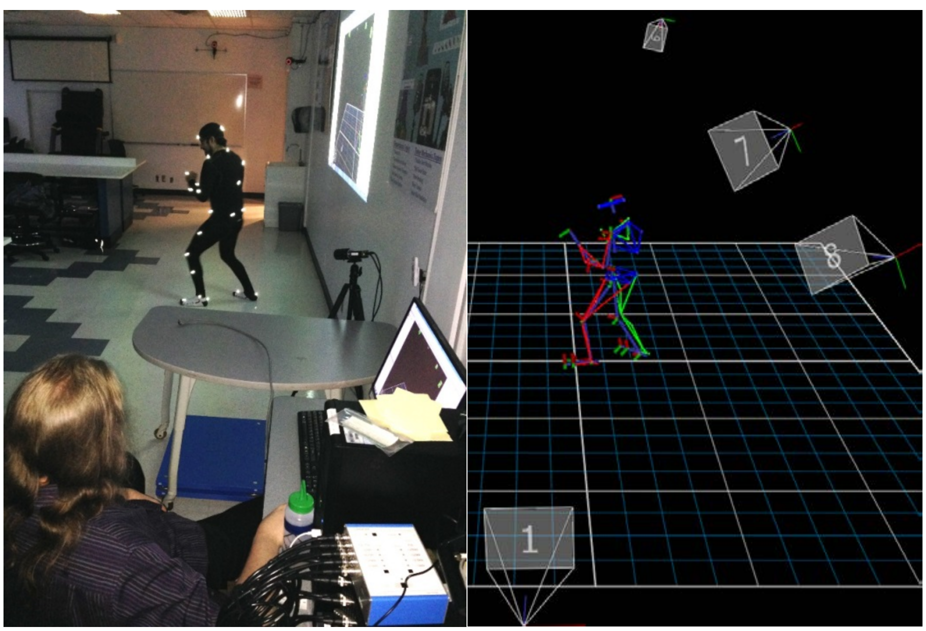


Figure 1: The motion capture system that the students used in the BME summer camp on Day 1 incorporates reflective markers that are monitored by eight infrared markers.

The complexity of this activity can be modified based on student interest. For a more engaged audience, 3D joint angles and linear velocity of the center of mass of the whole body can be calculated using Vicon software. Other applications for 3D motion capture such as computer generated animations in game design and movies can also be discussed. The students were also given the opportunity to play games that used markerless optical motion tracking (Microsoft Xbox Kinect®) and a ground reaction force measuring platform (Nintendo Wii Balance Board®). The students particularly enjoyed and appreciated this activity. Learning by observation is an excellent way to teach them about rudimentary biomechanics.

Anterior Cruciate Ligament (ACL) Reconstruction

Biomedical engineers work with clinicians to develop new medical devices and techniques that improve the treatment of injury and disease. One example is in the field of Orthopedics, which has an obvious connection to biomechanical design of total joint replacements and fixation devices that improve healing. The students were given the task go online to find an example of an Orthopedic company that produces one such device. They were encouraged to focus on the theme of ACL reconstruction surgery techniques. Next, they shared the device that they researched with the rest of the students and discussed the benefits as well as possible improvements. An online virtual knee replacement surgery demonstration (Edheads.com) gave the students an introduction to the steps in an orthopedic surgery. Using Sawbones model of a knee joint, the students performed an in-class ACL reconstruction with their group (Fig. 2)

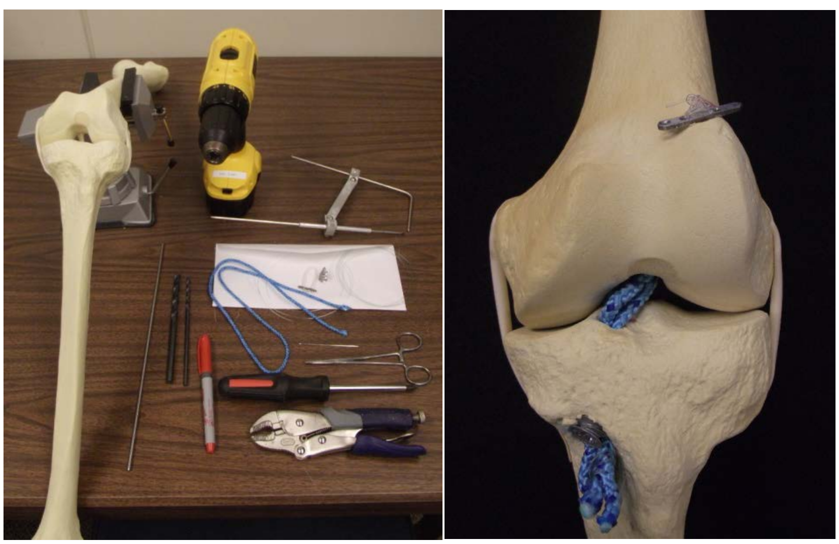

Figure 2: The images show the tools and materials used to simulate ACL reconstruction. The close up on the right shows a fixated knee after the activity.

Students learned how to diagnose an ACL injury by measuring the anterior-posterior laxity displacement and graft options that are available to match the normal stiffness and strength properties of the natural ACL. They used two of the fixation methods to attach the graft to the bones on either side of the knee. Finally, they checked the outcome of their surgery by retesting the laxity and also whether their knee retained its normal ranges of motion in flexion and extension. This group hands-on activities was popular although some of the students had to be instructed on safe usage of handheld drill.

Anthropometry Activity and Discussion

Basic anatomical terminology was introduced and related to human normal anthropometry. The students measured the segment lengths of their group members and used a 2D video analysis software program (Kinovia) to measure the maximum angles of each joint. This activity was used to highlight the slight variations in human anatomy and requirement for biomedical engineered devices and techniques to work with these variations. The reception for this activity varied across different groups. Some students did not have any experience with using technical software and the learning curve for 2D analysis disinterested them.

Biosensor and Medical Devices Introduction

Sensors are incorporated in all kinds of devices and technology. Biological and chemical sensors are used in many industries and are finding increasing use in personalized medical devices. At the start of day three, students were engaged in a discussion about the type of sensors they had interacted with since the time they woke up that morning. Students were asked if they had been an ER or a hospital and can name some of the routinely measured physiological parameters. The ensuing discussion was used to introduce important components of electrophysiological systems. A brief introduction to personalized medical devices was also given. Students were given seven mystery devices and were asked to work in groups to identify the device functionality. Some of the devices used were glucose sensors, medication cartridges, TempaDot® temperature sensor and a mock pacemaker. The number of devices in this activity can be varied and the student interaction can be promoted through a discussion of ideas such as device construction, marketing, safety and packaging.

Measuring Vital Signs

The Biosensor lab at LTU is equipped with BIOPAC Student Lab® which is a multifunctional system that includes hardware and software for life science and engineering education. The system was used to demonstrate the measurement of electrocardiogram (ECG). Students were divided in groups of three and given the task of measuring their ECG during rest and after performing various exercises. They observed the PQRST waveform synonymous with heart functionality and the increase in heart rate after exercise. The results were compared among different groups and also with that of a handheld ECG device that uses dry electrodes. Students realized the pros and cons of personalized devices and the tradeoff between convenience and accuracy. Students also used the BIOPAC system to measure blood pressure and a pulse oximeter to measure blood oxygen level. In such activities, any irregularities in measurement can be used to discuss proper device usage and the importance of clear device operating instructions. The critical importance of accurate measurements should be reiterated in such activities. Glucose monitor can be used as an example of a ubiquitous biosensor where accuracy is of paramount importance. The observable change in heart rate with exercise promoted student engagement, making the activity interesting and informative for the participants.

Building a Sensor

Several sensor platforms were considered and in the end a temperature sensor based on a simple thermistor was chosen. The reason for this was because of the ease of the electronic circuit and the high sensitivity of the temperature element. Students were provided written descriptions of the procedure which included pictorial identification of different parts such as the one shown in Fig. 3

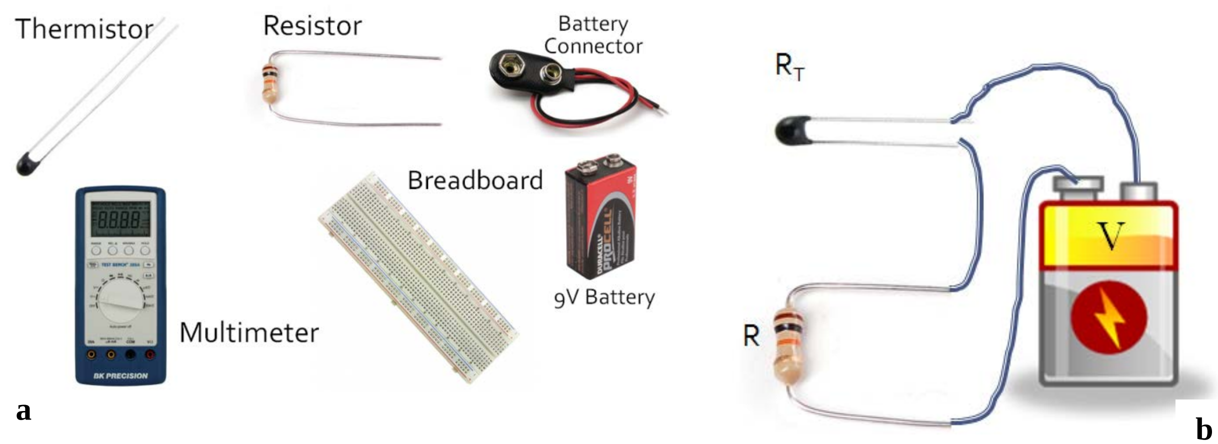


Fig. 3: ***a*** Each sensor kit had six components. A picture was included for easier identification. ***b*** The procedure also included a simple circuit diagram.

The procedure also included instructions on how to connect the components together and measure the voltage across the thermistor which can be translated into a temperature using a provided calibration curve. The students were provided with a formula that had to be algebraically manipulated to find the answer for the unknown $R_T$. Once this value had been found, they could then use the lookup table or the calibration curve to find the temperature value. The activity required them to measure the ambient temperature as well the change when holding the thermistor in between the fingers. They were also given a bulb, a digital and a strip thermometer to measure and compare the temperatures using these different types of sensors.

The students did not have any problems with identifying the components and then following instructions to create the simple voltage divider circuit despite the fact that most students were unfamiliar with electrical circuits and the current and voltage relationship (Ohm's law). However, the student groups had considerable difficulty in solving for the unknown $R_T$ value in the provided equation. Almost everyone had to be instructed on algebraic analysis which resulted in some student frustration as well as extra time than what had been allocated in the original plan. This can be avoided by providing the students with a EXCEL® worksheet which automatically converts their measured resistance value to a temperature value.

The unexpected outcome highlighted the hesitation faced by many high school students to tackle real world problems that may require mathematical analysis. Most students liked the activity, as indicated by exit feedback forms, demonstrating that they did not shy from a challenge. However, problem-based learning (PBL) [8] and application of core mathematical knowledge to real world problems is something that needs to be emphasized even at the secondary education level.

Understanding Brainwaves and Mindwave® Activity

Continuing with the theme of physiological measurements, the topic of electroencephalogram (EEG) and Neuroscience was introduced in a presentation. This topic was chosen because the state-of-the-art research in this area is seemingly *stuff out of science fiction movies.* Mind control and brain waves to control mechanical robots or spaceships is a popular theme in media. More recently, using brain waves to play videogames has gained a lot of attention, with some basic game offering already on the market. EEG related neurotechnology is a prime example where physicians work in close collaboration with engineers to come up with solutions to understand the human control of bodily functions and activities. Recent studies by research groups at Brown University as well as the new BRAIN initiative have garnered a lot of interest in this area.

These presentation of the topic included videos of such technology in action. The enabling technology that allows patients in locked-in states to control robotic arms using pure thoughts has a big *wow* factor. Such groundbreaking studies can serve as a great way to introduce BME to students who are interested in engineering but are also motivated by the desire to serve the humanity. The discussion on this topic included the complexity of understanding the most sophisticated computer known i.e. the brain. The topics of patient safety and using innovative medical devices to accurately read and decipher thoughts were a natural progression in the discussion.

The activity for this section included using two commercially available brainwave toys, the Mindwave® and Mindflex®. The Mindwave® works with a computer interface and using a simple single-electrode headset, the user can monitor concentration or relaxation (Fig. 4c). The Mindflex® toy can be used in *battle-mode* where the users can perform certain actions by exercising mental concentration. Many of the EEG toys are not very expensive (Mindwave® sells for about $100) and make it easier for students to understand sophisticated concepts.

Students were highly interested in trying each of the toy and group members eagerly battled against each other. The groups were given half an hour to test the effects of different activities on human concentration and the ensuing EEG signal. Many groups realized the inaccurate response of these toys and this spurred a healthy discussion about data interpretation. Still many students readily offered their own suggestions on how to increase concentration or relaxation. Faculty and staff volunteers interacted with groups during the activity and emphasized the intersection of medicine and engineering as a recurring theme in BME.


Fig. 4: Some of the commercially available EEG measuring devices and electrode setup. **a** IMEC Wireless EEG **b**. StatNet Disposable EEG **c**. Neurosky Mindwave **d**. MicroEEG **e**. Emotiv **f**. NeuroFocus

Miniaturization, Microfluidics and Lateral Flow Assay Activity

An important thrust in medical devices is miniaturization and personalization. Glucose sensors are an excellent example of this trend where the diagnostics are taking place at the point-of-care. One area where this trend has really taken off is in sports health and quantized self. There are many products that are being marketed by the traditional sport manufacturers to provide a wealth of physiological information such as user heart rate, blood pressure and temperature to name a few. These devices, although not regulated, are in common use and can be easily incorporated in summer camps to talk about miniaturization of medical devices. This topic was presented to the students and the pros and cons of having such technology readily available were discussed. Some of the students had not only heard about these devices but owned them and contributed to the conversation with their personal observations.

Using quantified self as a launching point, the critical components of medical devices and sensors were discussed through examples. Students engaged with the faculty about what components could be miniaturized and how this could be achieved. Analogies for reduction in size of other popular devices such as modern computers and cellphones can be easily used to hone in on this point. After introducing the topic of microfluidics, students were asked about the need for pumping fluids and the analogous components in human circulation system. Most students were able to identify the pump (heart) and piping (arteries, veins, capillaries) and appreciated the problems with mixing and diffusion at slow flow rates. Students were taken to a MEMS sensor lab where they observed laminar flow of different colored dyes in an H-cell flow channel. Two phase flow was demonstrated by creating micro air droplets of interspersed in water. A physical demonstration can work wonders in correcting perceptions about scale and size of interest in micron scale devices.

Students were given a pregnancy kit ($1 each) and asked to take it apart. A question was posed to them about what was the pumping mechanism in the device. Lateral flow assays (LFA) were then presented as a solution to miniaturization of pumping scheme by using the wicking power of absorbent substrates. Students used water solutions with dyes to observe how the solution wicked through the test strips. The conversation was extended by presentation of state-of-the-art LFA which allow detection of serious diseases such as Malaria and Cyptococcal Antigen. The activity related to this discussion asked them to create their own LFA and then observe the laminar flow and mixing at microscale. Student groups were given access to simple graphing software and instructions to make the boundaries of simple Y-shape channel designs. They were also given the liberty to draw/pick two designs of their own liking. These designs were printed and the channels were prepared using a procedure highlighted in the literature [9]. Thereafter, students used different colored dye solutions to observe the flow and mixing between colors. Many students chose to write their names for their own designs and this personalized element increased their interest in the activity. They were also able to take these designs with them which not only served as keepsakes from the summer camp. This activity was received enthusiastically and was ranked near the top in exit surveys.

Imaging Modalities and Student Hospital Tour

Medical Imaging is another area within BME which can be made accessible to students as instruments such as CT-scans, MRIs and X-Rays that are commonly found in hospital settings. Many students know about these instruments through their personal hospital visits. Staff members introduced these imaging modalities through presentation to the student at the start of the day 4. The students were given a chance to use MIMICS software which renders 3D designs and models of anatomical parts using 2D slices. BME department at LTU has a licensed version of the software and the system is used in the instruction of Imaging and Biomechanic classes. Students were informed how similar software can be used to enhance the understanding and interface between different anatomical features and can assist physicians during surgical procedures. The software comes preloaded with skull, hip joint and knee renderings and students were able to observe the intricacies of design by dragging and rotating the models. Accompanying presentation was important in helping them understand how computer generated models can be used in conjunction with actual images to get a better understanding of injury and disease states.

LTU has access to an Environmental Scanning Electron Microscope (ESEM) that was bought through and NSF MRI grant. While ESEMs are not common tools for diagnosis in medical facilities, they do provide high magnification images and allow observation of minute details. After the morning presentation and software demo, student groups were shown the ESEM and a live demonstration of pulling apart a strand of hair was given. Similar activities can be done with other imaging instruments based on access and availability, focusing on need to image non-invasively with high resolution. Biomedical Engineers are continually working with technologists to enhance instrument functionality by improving the software and hardware. There are many online resources and electronic media that can be included in accompanying presentation and discussions. Students were also taken for a tour to a radiology facility at St. John, Providence Hospital in close vicinity of LTU where a resident radiologist showed them commercial MRIs and CT-scanners. The tour consisted of brief stops at multiple imaging modalities. Students were able to observe the basic components of an X-ray and MRI machines. They also saw the operation of an ultrasound device as the radiologist demonstrated the device usage on a student volunteer from the summer camp. The physician explained surgeries performed at the hospital and how the imaging devices were used to assist in these surgeries. The students made a final stop at an orthopedic research lab and also observed simulation dummies which are used to teach medical interns.

The hospital tour was one of the highest ranked activities. As a part of the summer camp, tours to manufacturing and hospital facilities not only break the monotony of presentation/activity combination but can also give the participants a chance to observe usage of many of the engineered products. Tours and technology-in-action type activities allow students to better understand the future job opportunities and required skills for success and are therefore highly recommended.

General Observations

- In order to increase student engagement, it is necessary to include open-ended questions during presentations and inviting student responses. For example, a simple slide comparing fluidic architecture and desire for equal flow rates garnered correct responses from most students (Fig 5).

Fig. 5: Students were asked which fluidic channel will have equal flow in all legs and why?

- A combination of presentation and activity should be used in summer camps. The presentations should not last longer than 15-20 minutes and should be interspersed with open-ended questions and techniques to increase discussion type format.
- The activities should focus on one or two key concepts as including any more tends to only confuse the students. The instructions for activities should avoid too many scientific terminologies.
- The instructors and faculty members should take the time to explain the procedure for activities and should work with groups while students perform the activity.
- Groups should include ideally two and no more than three students as any more inadvertently cause some of the students to disengage during the activity.
- The presentations and activities should include a variety of media and demonstrations and references to popular science are well appreciated.
- The activities requiring simulations and computer demonstrations should be tested beforehand to avoid technical difficulties which can disrupt the flow and distract the students.
- The tours work very well and should be included during the middle of the week to break the monotony of lab activities and presentations.

Student Feedback

At the end of the summer camp, students were asked to rate the overall satisfaction with the camp and if they would recommend it to others. Of the students that responded in the exit surveys, 71% of student rated the summer camp as good and 57% said that they will probably recommend the camp to others. The students were also surveyed about the specific hands-on activities and provided vital feedback about the ones that were popular and the ones which were not well-received. The popularity of a specific activity is both indicative of student interest as well as the communication and instructions provided for the activity.

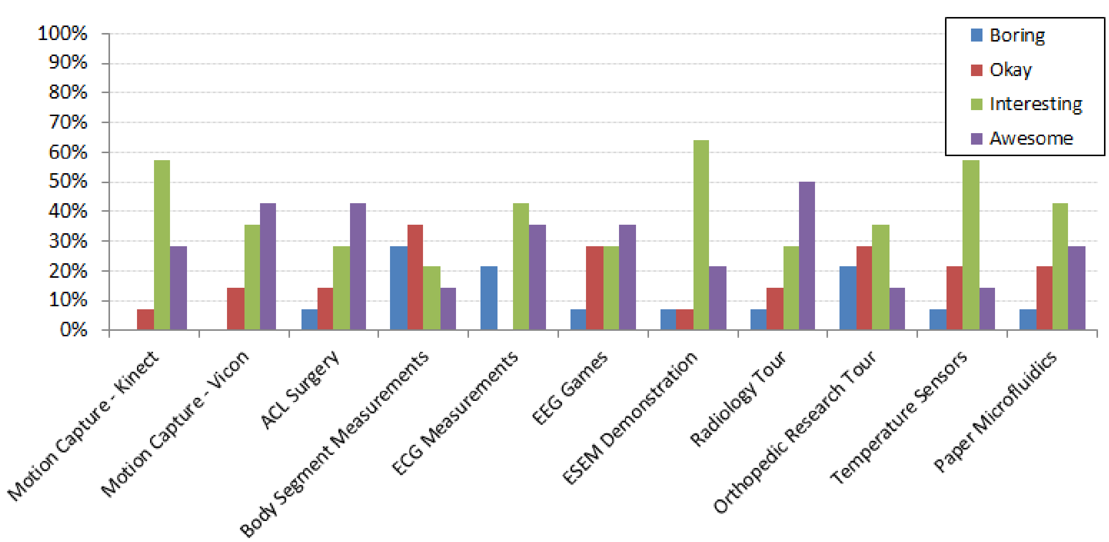


Figure 6: The results of how the activities were received by the BME summer camp participants.

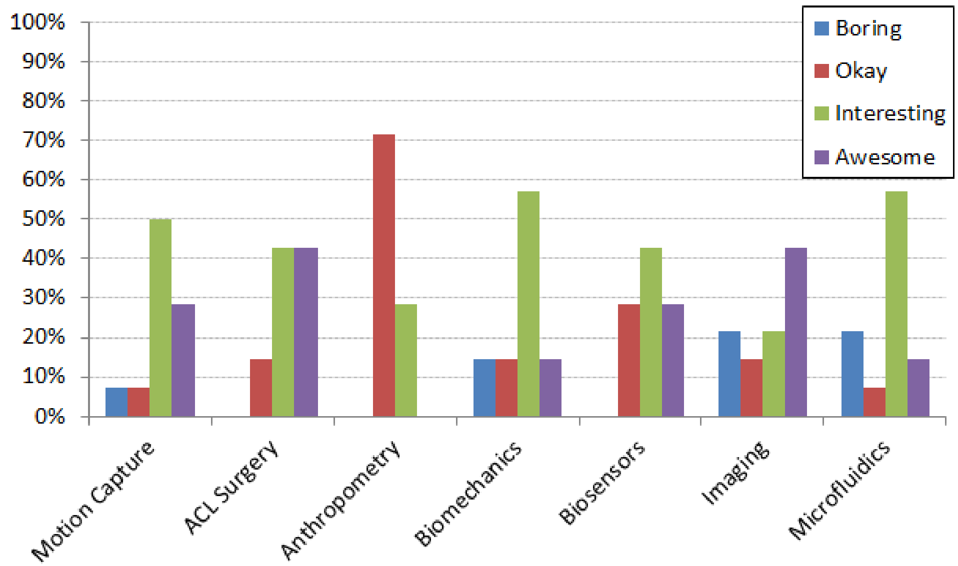


Figure 7: The results of interest in the different topics presented during the BME summer camp.

In our assessment, some activities can be made more informative by improving the set up instructions (Temperature Sensor) while others require better setup presentations (Body Segment Measurement and Foot Arch Measurement – data not shown). The assessment results indicated that the specific activities affect the student interest in the topics discussed. When the students found the activity interesting, their interest in the corresponding topic also increased. Generally speaking, activities that allowed personalization (Microfluidics) or included gamification (EEG, Motion Capture) were more popular. In future, we will employ surveys at the start and end of each day to better gauge the effectiveness of the different activities.

## Conclusion

Ultimately, the success of activities in a BME summer camp lies in providing a glimpse of the basic engineering design tools and instrumentation that are used in medical settings. The purpose of these camps is also to generate enthusiasm in the participants to pursue a postsecondary degree in an emerging engineering field that aims at enhancing the quality of life. Obviously, the activity for each topic cannot be a game but the summer camp instructors and coordinators should aim to strike a balance between presentation and activity. By choosing a host of different topics, the camp can not only cater to students with different interests and backgrounds but will provide the participants with a broad overview of BME, which is the primary reason for most students attending such a camp.

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