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Breaking Barriers: Empowering Girls in STEM with Hands-On Learning

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Breaking Barriers: Empowering Girls with STEM Education Using Hands-On Learning

Abstract: Women currently represent only 34% of the workforce in the science, technology, engineering, and math (STEM) fields. This gender gap is particularly significant in some of the fastest-growing and highest-paid jobs, such as computer science and engineering. To address this issue, various strategies have been implemented to increase female success in STEM education. At our university, we have offered STEM outreach initiatives aimed at fostering female students' interest, confidence, and active involvement in STEM fields, adopting the hands-on approach embraced in our curriculum.

In 2023, our institution hosted a STEM workshop welcoming female students from grades 6-12 enrolled in the Ron Burton Training Village (RBTV) program. The workshop consisted of five STEM modules, with each module dedicated to a specific field: Electrical Engineering, Computer Engineering, Mechanical Engineering, Math, and Engineering Design Thinking. This paper details the implementation of the three Engineering Modules: "Building an ECG Circuit" for Electrical Engineering, "Building a Digital Water Temperature Thermometer" for Computer Engineering, and "Material Property Testing" for Mechanical Engineering.

At the conclusion of the event, attendees were invited to participate in a survey to assess their STEM experience and to offer suggestions for program enhancement. This paper presents the survey findings and discusses the challenges encountered and potential improvements for future STEM outreach events, considering the valuable insights gathered from the students' feedback.

Index Terms – Outreach, Female Students.

1. Introduction

The U.S. science, technology, engineering, and mathematics (STEM) workforce is fundamental in propelling innovation and making significant contributions to national growth. The ever-growing landscape of science and technology continually reshapes the job market, creating an increasing need for individuals skilled in these technical fields [1]. This escalating demand has resulted in a notable increase in the number of STEM professionals [2]. In 2021, 34.9 million individuals (about twice the population of New York) engaged in STEM occupations, comprising 24% of the U.S. workforce, up from 29.0 million in 2011. Notably, within the STEM workforce, approximately two-thirds (65% or 22.6 million) were men, while about one-third (35% or 12.3) were women in 2021 [3]. Several research studies have investigated major barriers that prevent female success in STEM fields [4],[5]. Male domination of STEM careers, lack of awareness of educational and career opportunities, a lack of female mentors/role models, minimization of barriers, personal expectations, the time required to become proficient in a STEM field, and lack of encouragement from men, are just some examples of obstacles identified in [6],[7].

Despite women remaining underrepresented in STEM occupations compared to men, their presence in this field has been steadily increasing. Over the past decade, there has been a 3-percentage point rise, from 32% to 35%, in the proportion of women in the STEM workforce from 2011 to 2021 [3]. This growth in women's participation within the STEM workforce signifies progress toward gender diversity in these critical fields, emphasizing the need for sustained efforts to foster inclusivity and equal opportunities for all individuals interested in pursuing careers in STEM. Various institutions at local, federal, and individual levels have developed policies to address gender-based discrimination [7]. The U.S. has consistently supported initiatives promoting women's education in STEM disciplines, with studies showing that early education initiatives positively influence girls' interest and success in STEM fields [8],[9]. Consequently, numerous schools across the U.S. are actively supporting STEM-related extracurricular activities aimed at attracting, empowering, and retaining women in STEM disciplines [10], [11].

Wentworth Institute of Technology (WIT), located in Boston (MA), has played an active role in multiple STEM outreach initiatives to promote female students and underrepresented communities into STEM fields, providing hands-on experiences. Programs like the Girl Scouts STEM Day (since 2014) for 4th or 5th-grade students [12], the STEM program for High School Girls- (since 2016) [13], and a new STEM program (initiated in 2020) for first year and sophomore female high school students from a private girls' high school [14] have been conducted. In 2021 WIT started a new collaboration with Ron Burton Training Village (RBTV). RBTV program runs a STEM activity for students grades 6-12. In this program, female students attended a different STEM experience every weekend and concluded each year with a capstone project. The initial workshop, held by our university in March 2021, was conducted via Zoom due to the COVID-19 pandemic [15]. Encouraged by its success, the first in-person event took place in March 2023, featuring a one-day workshop with five STEM modules—Electrical Engineering, Computer Engineering, Mechanical Engineering, Math, and Engineering Design Thinking.

This paper aims to present an overview of the workshop and specifically focuses on the preparation and implementation of three Engineering modules: Electrical, Computer, and Mechanical. Additionally, it discusses survey data to highlight insights that emerged during the workshop that could contribute toward the enhancement of our STEM outreach programs and towards the initiation of similar initiatives in other Schools.

2. Workshop

The event was a one-day workshop held at WIT from 9:00 am to 3:00 pm, with a total attendance of 67 female students ranging from 6th to 12th grade. The distribution of attendees by grade was as follows: 13% 6th grade, 18% 7th grade, 19% 8th grade, 26% 9th grade, 11% 10th grade, 11% 11th grade, and 2% 12th grade. Participation in our event is entirely voluntary for students enrolled in the RBTV program, as they select the STEM activities they wish to engage in throughout the year. It is noteworthy that the number of attendees has significantly increased since last year; in 2022, only 38 students participated in the online workshop, compared to the 67 attendees in 2023. The workshop began with a brief introduction, followed by a short physical activity session. Its primary focus was to offer female students an immersive, hands-on experience in STEM subjects. The key strength of the workshop offered lies in its emphasis on practical and experiential learning, which closely aligns with our school's mission.

The objective of providing hands-on experience is to create a supportive environment where students can explore, experiment, encounter setbacks, and learn from them, thereby fostering a growth mindset and critical thinking skills. Rather than viewing failures as discouraging, students are encouraged to see them as opportunities for growth and learning. This approach helps enhance students' confidence, interest, and motivation in STEM subjects.

The workshop encompassed five distinct STEM modules: Electrical Engineering, Computer Engineering, Mechanical Engineering, Math and Data Analysis, and Engineering Design Thinking. Each module spanned 40 minutes and comprised an initial lecture aimed at familiarizing female students with the specific engineering field and topic. The remainder of the session was dedicated to hands-on activities.

Faculty members from respective disciplines conducted each module, accompanied by 2-3 undergraduate engineering student volunteers. These volunteers aided in setting up the lab and necessary equipment, actively engaging with female students during activities, addressing queries, and assisting with any technical issues they encountered during the laboratory activity. It is important to note that both faculty members and student volunteers underwent training to effectively execute their roles during the workshop.

3. STEM Modules

Every year RBTV students learn new topics in the STEM field based on the UN Sustainability Development goals [16]. In 2023 the focus was on UN Goal 9: Industries, Innovation, and Infrastructure. This goal aims to establish resilient infrastructure, promote sustainable industrialization, and encourage innovation. Potential experience topics were sensors, material testing, human-machine interface, people to technology, healthcare optimization, internet of things, etc. Consequently, the STEM engineering activities were crafted and tailored around these themes.

The Computer Engineering module, titled "Building a Digital Water Temperature Thermometer," and the Electrical Engineering module, titled "Building an EKG Circuit," were designed to underscore the significance of Man-Machine Interface systems in industrial automation and healthcare applications, respectively. Meanwhile, the Mechanical Engineering Module, "Material Property Testing," aimed to demonstrate how individuals can interact with and adapt to emerging technologies. Below, a more detailed description of the modules is provided to detail their objectives and the learning experiences they offered.

3.1.Computer Engineering Module: Digital Water Temperature Thermometer

In the Computer Engineering module, The Digital Water Temperature Thermometer project was selected for students to experience programming, microcontroller, and electronic devices. The goal of this project was to let students enjoy the activity, learn about system automation, learn about programming and electronic devices, give them confidence about this topic, and instill interests in the STEM field. To increase students' confidence, this module was broken down into multiple tasks so students could experience and get a better understanding of how each component works.

Task 1. Basic coding and microcontroller
In this task, students learned how to write a program to control Arduino Uno board and display the results on the LCD screen. Due to limited time, the LCD screen was already connected to the board and some parts of the code were provided. Students only needed to make changes in a

program. To create an enjoyable and entertaining experience, this task started with teaching basic concepts of how Arduino code works. Then, students were asked to make changes in a program and display their names on the LCD screen. Once they completed the first section for the task, students were asked to make changes to the other part of the code, and to observe and discuss what they found (e.g., reduced the accuracy of the display, changed the delay time etc.). This task increased students' attention and self-confidence in programming.

Task 2. Temperature Sensor

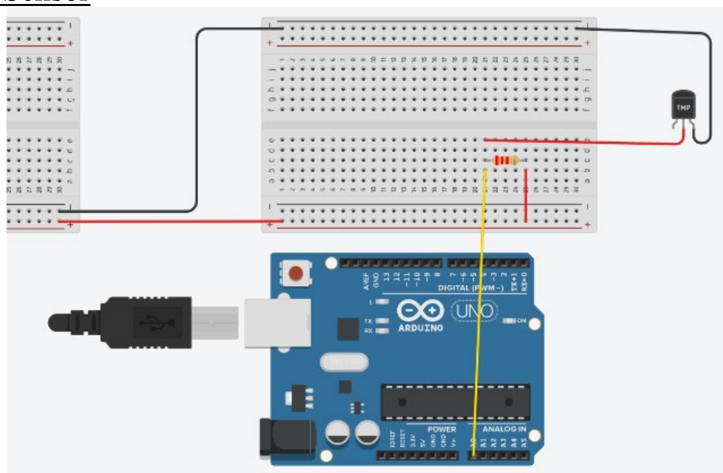


Fig. 1: Temperature sensor circuit

In the second task, the goal was to let students have experience with electronic devices, particularly with resistors and the temperature sensor. At the beginning of this task, a temperature sensor, breadboard, wires, and resistors were provided to students. Then, there was a brief explanation about how breadboards work and how to assemble a circuit based on a given circuit diagram. Students had to assemble a circuit, upload a given code to Arduino, and read the temperature from the LCD screen. The given code in Task 2 uses a similar concept as shown in Task 1; it includes a few lines for temperature calculation and a few lines to display results on the LCD screen. Students could easily understand how the code worked. Fig. 1 presents a circuit diagram that students had to assemble. After students correctly connected a circuit, cups filled with water at different temperatures were provided for students to test the results. From this task, students could experience how electronic circuits would work and they could see how to relate a technical problem to their everyday life.

Task 3. LED

Task 3 is a combination of task 1 and task 2. If students could complete task 2 before the end of the session, they had an option to continue working on task 3. In this task, an LED was added to the circuit to indicate that the water temperature is above its threshold value; 75 degrees Fahrenheit was the initial value provided to the students. Similar to tasks 1 and 2, students had to assemble a circuit, run a given code in Arduino, as illustrated in Fig. 2, and observe the results. Once students completed this task, the presenter discussed their findings with them, and asked them to make changes in the code, to test their circuit, and to observe the behavior of a circuit. The changes that students were asked to make were the threshold temperature, delay, and the condition in the program. More than half of the groups could complete task 3 and they were very

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(12,11,5,4,3,2); // initialize the LCD display inputs

int threshold_temp = 75; // set a threshold variable to alert the user if the temperature is too high
float  sensor_reading, temperatureK, temperatureC, temperatureF; // initialize variables to store the temperatures

void setup() {
  lcd.begin(16, 2); // itialize the LCD display
  lcd.print("Temperature ="); // print on the screen
  pinMode(8, OUTPUT); //set digital pin #8 to OUTPUT to torun on the LED
}

void loop() {
  delay(1000); // delay for 1 second
  sensor_reading=(analogRead(A0) * (5000.0/1024.0));// this is a voltage reading from analog pin A0
  temperatureK = sensor_reading/10.0;      // Convert the voltage reading to Kelvin beacuse the s
  temperatureC = temperatureK  - 273.0;    // Convert from Kelvin to Celsius
  temperatureF = (temperatureC * 1.8)+32.0;   // Convert from Celsius to Fahrenheit

  lcd.setCursor ( 4, 1 ); // itialize the LCD display
  lcd.print(temperatureF,2); // print on the screen the temprature value
  lcd.write ("F"); // print on the screen the unit measure

  if(temperatureF > threshold_temp) // if the temperature is greater than the threshold value we want to turn on the LED
  {
    digitalWrite(8,HIGH); //switch LED on
    delay(1000); // delay for 1 second
    digitalWrite(8,LOW); //switch LED off
    delay(1000); // delay for 1 second
  }
  else
  {
    digitalWrite(8,LOW); // if the temperature is less than the threshold value we want to turn off the LED
  }
}
```

Fig. 2: Arduino code for Task 3

satisfied with their results. For the group that did not achieve task 3, they wanted to continue working on it, however, due to time constraints, they were not able to complete the activity.

3.2.Electrical Engineering Module: EKG Circuit

Engineering is the backbone of modern society. Without it, key infrastructure that powers our world, like computing, communication, construction, and transportation, would cease to function properly. It is indeed imperative to understand how deeply we may depend on this field, which includes a wide range of disciplines, to make the world work. It takes a *creative* and *curious* engineer, one who truly notices the bridge between scientific methodologies and real-life

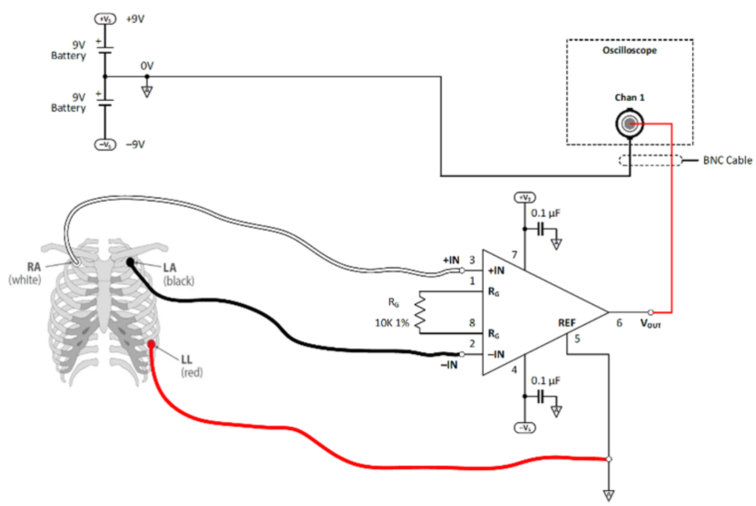
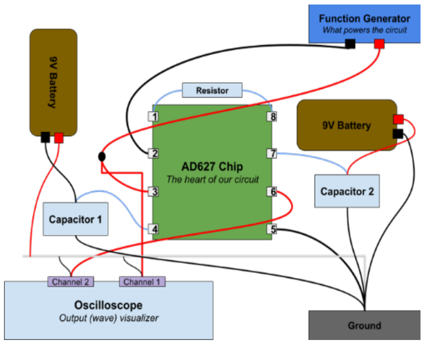
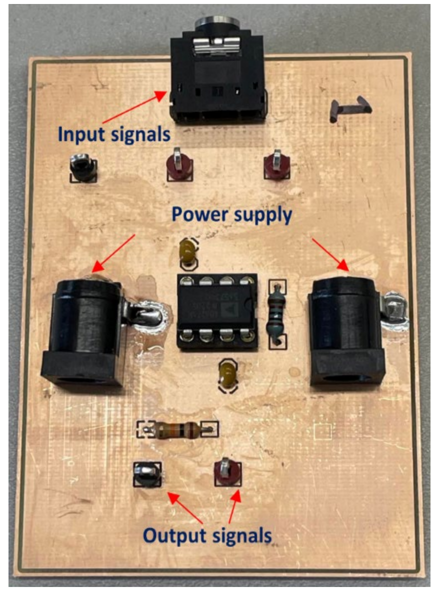


Fig. 3: Schematic for the EKG circuit showing connections to the body.





a) b)

Fig. 4: (a) Block and connections diagram of the EKG circuit, (b) Built PCB of the EKG circuit used in the electrical engineering module.

problems, to help advance the world. Thus, to develop professional skills, one must begin by keenly observing the world around us. In the hopes of empowering future engineers to notice the interconnected systems at play in our world, an Electrocardiogram (EKG) circuit for the Electrical Engineering module was developed. The circuit diagram of an EKG circuit with connections to the body is shown in Fig. 3 [17]. The circuit includes an instrumentation amplifier to boost the bioelectric potentials associated with the electrocardiogram signals.

The RBTV attendees were in the 6-12 grade range and were not expected to have prior knowledge of electrical circuits and schematics. Therefore, to simplify the diagram shown in Fig. 3 for the audience, and to convey the information regarding the interconnection of the electrical components of the circuits effectively, a block diagram of the system was developed that is

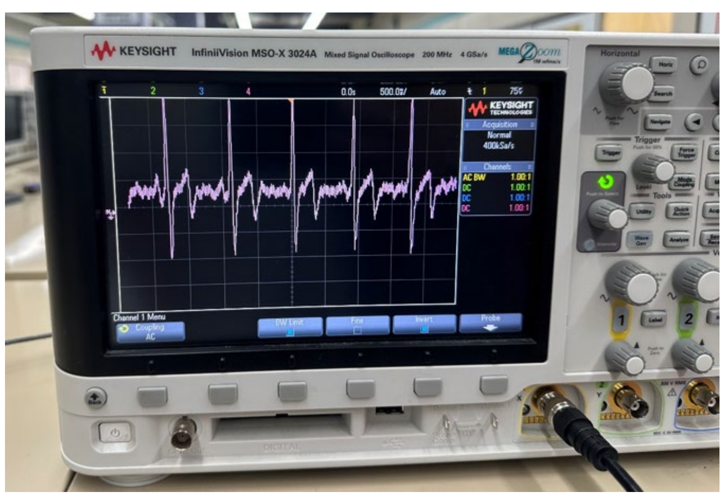


Fig. 5: A sample EKG (heart) signal displayed on the oscilloscope.

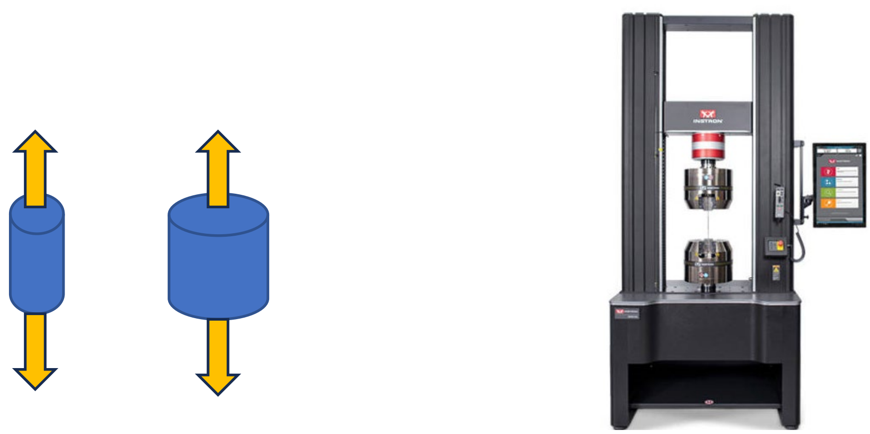
shown in Fig. 4 a) [17]. Additionally, the RBTV attendees were not expected to have prior knowledge of using a breadboard. Given that the module length – 40 minutes each – would not be sufficient time to teach basic breadboarding and allow enough time to set up the circuit, Printed Circuit Boards (PCBs) of the circuits were produced for the attendees.

The Electrical and Computer Engineering (ECE) labs of the School of Engineering (SoE) at our university contain PCB (Printed Circuit Board) router; a milling machine that is fully equipped to create high-quality boards. With the help of an Electrical Engineering (EE) undergraduate student, an ECE lab technician and two ECE faculty members, PCB circuits of the EKG circuits were built at the SoE. These PCB boards (Fig. 4 b)) were distributed to the students who participated in the RBTV Electrical Engineering module to perform the EKG experiment. Students connected the circuits to their torso or their forearms using the BIOPAC-EL503 pads to view and display their heart signals on an oscilloscope. In Fig. 5, a sample of what they observed as a heart signal is presented. The module provided an opportunity for students to be introduced to electrical circuits and their applications; where the art of applying scientific theories to real-world scenarios becomes a tool to solve a problem.

3.3.Mechanical Engineering Module: Material property test

In our daily lives, various machines play crucial roles, each composed of varied materials carefully selected based on their specific properties. For structural applications in bridges, ships, automobiles, airplanes, and more, the tensile properties of the metal material set the criteria for a safe design. Engineers face the challenge of selecting appropriate materials for these machines, how do they face the challenge? In this workshop, the fundamental concept of materials property was introduced; students then engaged to conduct tensile tests on two specimens.

In the initial phase, the concept of stress was introduced to the students through an engaging exercise. They were presented with two scenarios involving samples crafted from the same material but with varying dimensions, as depicted in Fig. 6 a). The thought-provoking question posed to the students was: "If you attempt to break these two samples by pulling them in opposite directions, would you need to apply the same amount of force?" In response, all students unanimously acknowledged that a greater force would be required to break the thicker sample.

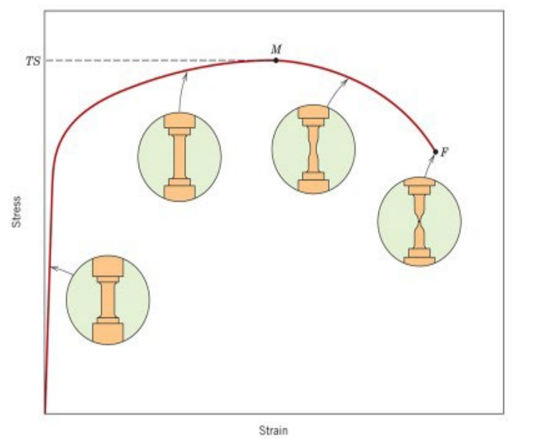


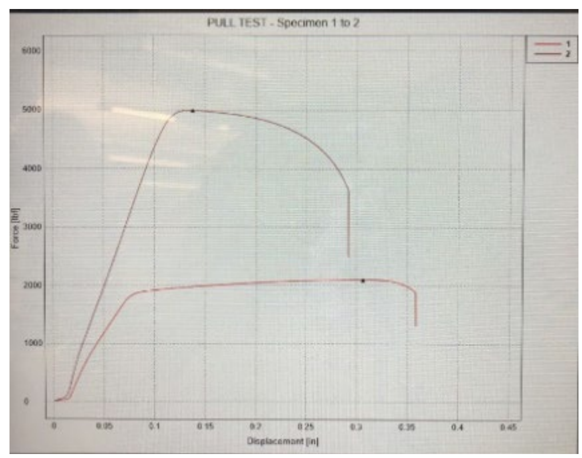
a) b)

Fig. 6: a) Two samples; b) Instron Universal Testing Machine

Following this, a second question was presented: "Considering that the two samples are made from the same material, shouldn't their properties be identical? Why are the forces different?" The students explained that the sizes of the samples are different. This realization led the students to the understanding that force and size alone cannot be used as direct measures of a material's properties. Instead, the significance of considering the force and cross-sectional area ratio emerged as a more accurate gauge for evaluating material properties.

After discussion, the experiment was conducted. The Instron Universal Testing Machine (illustrated in Fig. 6b) was introduced, emphasizing its significance in conducting tensile tests. Safety considerations were highlighted before a demonstration on how to use the machine for testing. Students, then divided into groups of four, utilized the Instron machines to test aluminum and steel samples. Throughout this process, they observed dimensional changes in the specimens, as illustrated in Fig. 7 a). The final test results shown in Fig. 7 b) indicated that, for specimens of the same size, steel required a larger force to break, signifying higher tensile strength compared to aluminum.





a) b)

Fig. 7: a) Specimen geometry changes; b) Testing results

3.4.Discussion

Engaging students in STEM outreach through the utilization of laboratory equipment provides a valuable opportunity for them to immerse themselves in hands-on experiences with modern tools, conducting real testing and experiments. The workshop ran smoothly without encountering any pitfalls, providing an exciting and enjoyable experience for both students and staff. For instance, during the Materials proper testing activity, students expressed surprise and fascination as they used the equipment, particularly when breaking the sample with the machine. During the computer engineering module, students were excited because they felt that programming and electronics are not as difficult as they thought and their confidence in programming and electronics has increased. Many students captured the moment by recording videos of the testing. This not only highlights the excitement generated by practical experimentation but also underscores the potential for such experiences to leave a lasting impression on students, fostering a deeper interest in STEM disciplines.

4. Survey

At the end of the workshop, The RBTV program coordinators requested attendees to complete a survey. This survey aimed to evaluate the experience itself, the content of the STEM modules, and the strengths and the weaknesses of the workshop. A response rate of ~ 40% was achieved. The survey comprised of the following questions:

Q1. How would you rate the STEM Experience?
Q2. This Experience increased my interest in STEM.
Q3. This Experience increased my knowledge about our School.
Q4. What did you like most about the STEM Experience?
Q5. What did you learn during the STEM Experience?
Q6. How can the STEM Experience be improved?

To answer the first three questions, female students were provided a Likert scale of "1" to "5" that respectively corresponded with "Strongly Dislike" and "Strongly Like" for Q1. However, the scales of "1" to "5" associated with "Strongly Disagree" to "Strongly Agree" for Q2 and Q3.

5. Results and Discussion

Results obtained from questions Q1, Q2, Q4, Q5, and Q6 are illustrated below. Results of Q3 are omitted in this paper because they are out of scope of this paper.

Fig. 8 shows the ratings of the overall STEM experience on a scale from 1 to 5. Notably, 59% of the attendees strongly liked the workshop and none of the students disliked the STEM activity. An average rating of 4.4 out of 5 was achieved. This average rating demonstrates that girls enjoyed the activity, and this first in-person workshop can be considered successful since the

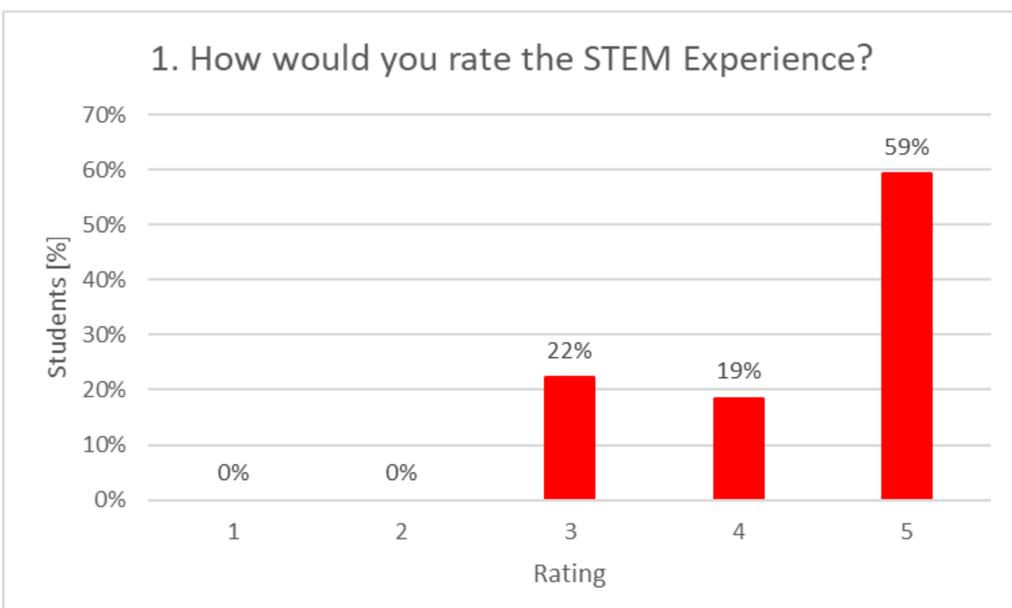


Fig. 8: Survey Results Q1

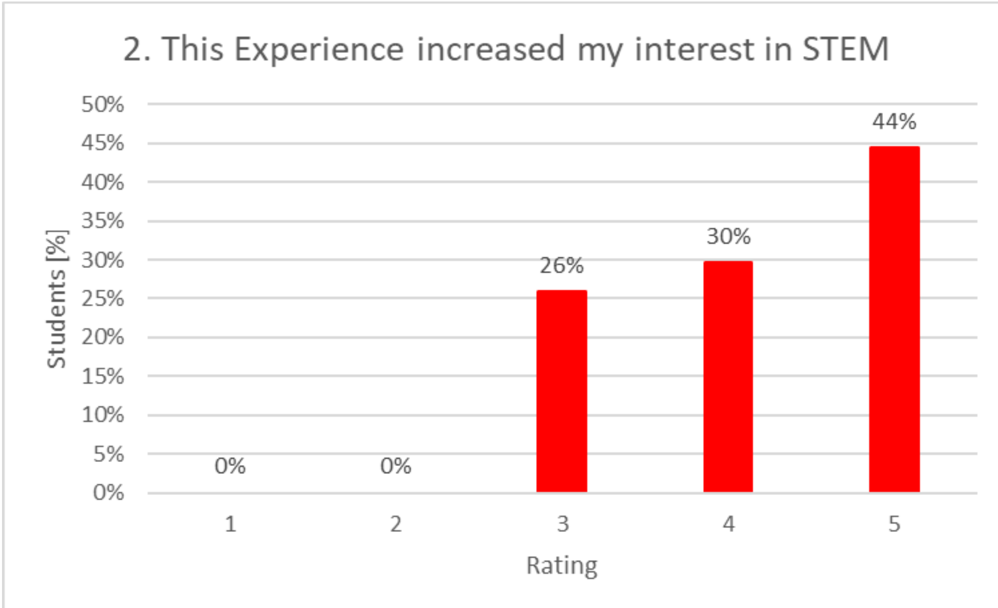


Fig. 9: Survey Results Q2

ratings were all equal or above 3. The primary objective of STEM outreach activities is to motivate, foster interest, and retain females in STEM fields. Consequently, we sought to investigate whether the workshop effectively achieved these desired outcomes.

Fig. 9 illustrates the ratings on a scale from 1 to 5 regarding whether the workshop enhanced students' interest in the STEM field. A noteworthy 74% of attendees agreed or strongly agreed that their interest increased, while 26% remained undecided. The significance of this relatively high percentage of undecided students prompts further investigation into the reasons for their neutral response. Possible factors contributing to this undecided response include the complexity or lack of challenge in laboratory activities, unappealing topics covered in STEM modules, insufficient time per module for a comprehensive understanding or completion of exercises, and a lack of engagement during the workshop, etc., To gain deeper insights into the outcomes presented in both Fig. 8 and Fig. 9, the survey incorporated open-ended questions.

Fig. 10, presented as a pie chart, highlights the aspects of the STEM experience that female students enjoyed the most. Notably, 69% of the respondents expressed enjoyment in the hands-on approach of our activities and the interactive experiments, aligning closely with our school's mission of delivering hands-on, experiential, and cooperative education. A significant portion, 21%, appreciated the contributions of volunteers and staff who participated in and coordinated the event, as well as the individual activities that provided opportunities for real-world connections. It is worth mentioning that the remaining students found satisfaction in aspects not directly tied to STEM activities, such as the food and the chance to socialize with friends. This comprehensive view provides valuable insights into the diverse preferences and positive experiences of female students during the STEM program.

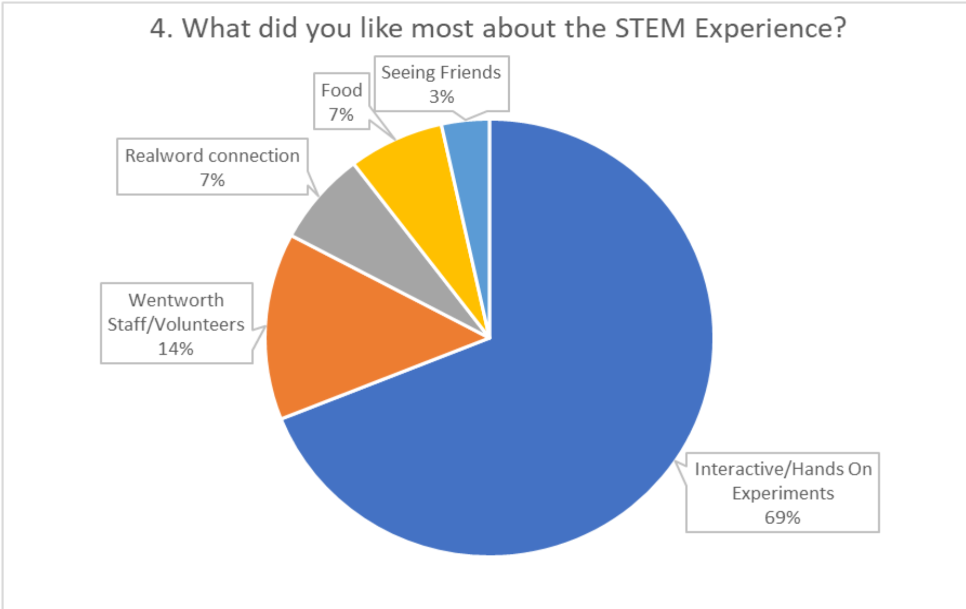


Fig. 10: Survey Results Q4

Fig. 11 presents the survey results for Q5. This open-ended question aimed at understanding how participants believe their knowledge improved post-workshop and identifying the information/skills they acquired. Notably, 23% of girls perceive an increase in their knowledge of the STEM field. The majority, approximately 64%, retained skills acquired during the Computer, Electrical, and Mechanical Engineering Module. Specifically, 23% learned to connect and code a system with a water thermometer, 22% grasped the working principle of a heart rate monitor, and 19% acquired knowledge about properties and characteristics of metals. These outcomes underscore the effectiveness of the three engineering modules, as a significant portion of the girls express confidence in having acquired fundamental engineering principles and

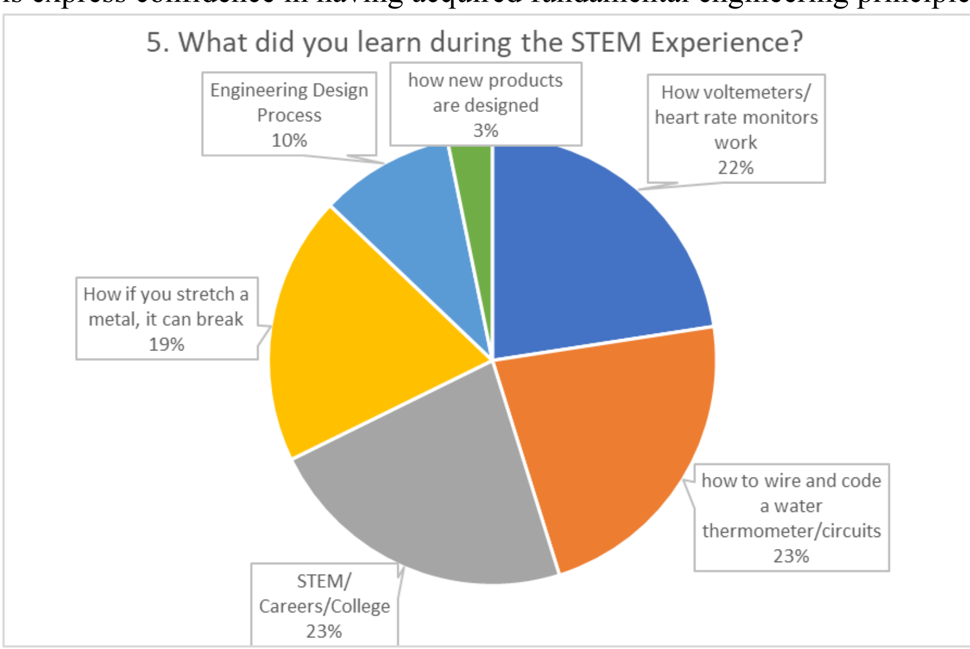


Fig. 11: Survey Results Q5

concepts. The positive response depicted in Fig. 8 confirms that the event had a substantial impact on the STEM knowledge and experience of the female students attending the workshop. However, the 26% of girls uncertain about whether the workshop increased their interest in STEM, raises concerns regarding the enhancement of the overall STEM experience. Further investigation is needed to address these concerns and improve the workshop's effectiveness.

Fig. 12 displays a summary of the results of question Q6. Surprisingly, 41% of participants had no suggestions for improvement; some students enjoyed the activity so much that they expressed their desire to return in the future. Another 41% proposed enhancements related to the workshop itself, such as incorporating a school tour and allocating more time to artistic and physical activities. Notably, only 10% expressed a desire for more in-depth exploration of each activity, an understandable request given the time constraints of the STEM activities. The suggestion for more detailed engagement is particularly noteworthy, as it highlights the challenge posed by the limited 50-minute duration for each module. This constraint may impede participants from fully grasping and completing the engineering activities, potentially impacting their attention and self-confidence in STEM disciplines. To address this concern, future workshop implementations will consider adjusting the schedule and the length of the STEM modules. A proposed solution involves merging the Electrical and Computer Engineering modules into a single session. This allows for additional time that can be allocated among the three engineering modules. This adjustment aims to give instructors more time for detailed instruction and provides students with ample time to comprehend and successfully complete the activities.

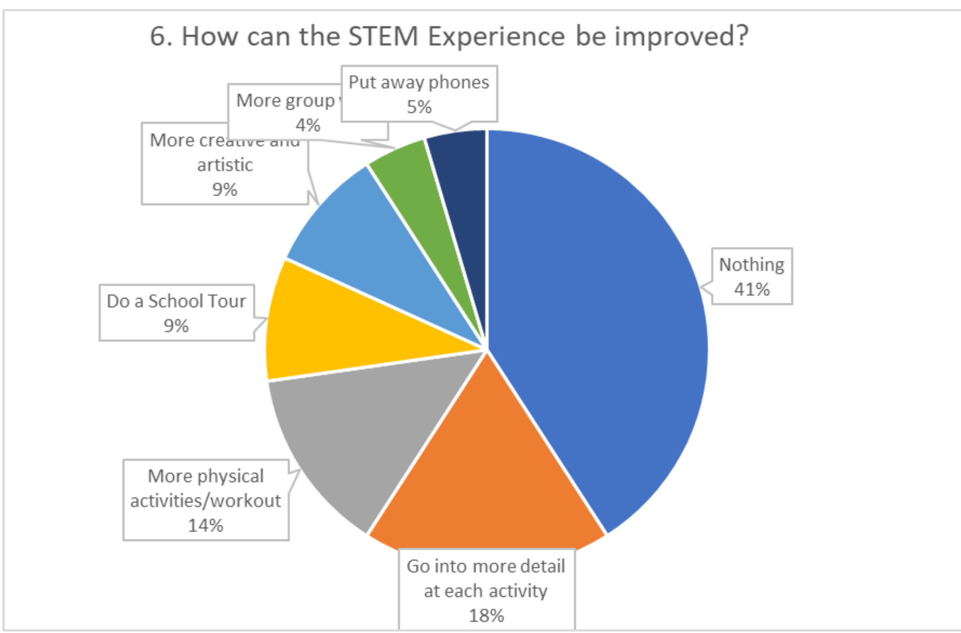


Fig. 12: Survey Results Q6

To support results illustrated in Fig. 12, some of the follow-up students' answers to Q6 are presented in Table 1. As previously discussed and illustrated in the first comments below, some attendees clearly stated that they enjoyed the activity and found it engaging and that to the best of their knowledge no improvement is needed.

Table1: Survey Answers

“No, the STEM Experience doesn't need to be improved it an amazing that's able to empower, motivate, and teach students if they are interested in the STEM field.”
“I thought this experience was a great opportunity and nothing that I know of needs to be improved.”
“I don't really know all I know is that it was so fun.”
“More physical activities”
“This Experience was great! I would love to take another trip to your School and learn even MORE!”
“I think we should have more time for each station so we can fully understand the topic that we are working on.”

6. Conclusion

Promoting early exploration of STEM among girls is crucial, serving as a potential stimulus to inspire continued interest in STEM subjects throughout their academic journeys. Our school is committed to offering outreach activities that expose girls to STEM education, providing hands-on experiences with the overarching aim of nurturing interest and building self-confidence.

In Spring 2021, our university established a collaboration with RBTV. This paper focuses on the inaugural in-person STEM workshop hosted at our school in March 2023, highlighting the three engineering modules: Computer, Electrical, and Mechanical Engineering. Survey data indicates that female students not only enjoyed the workshop but were particularly enthusiastic about the hands-on and experimental activities offered. This underscores the transformative impact of experiential and hands-on learning, instilling excitement and curiosity that can contribute to cultivating more engaged, motivated, and passionate learners in STEM fields.

The majority of attendees expressed gaining knowledge about the explored topics during the activity, exhibiting excitement and curiosity throughout. One of the girls was so inspired and loved the experience so much that she wrote a report about it. The success of the first in-person STEM workshop signifies the potential for future outreach events in collaboration with RBTV and other partners. Insights from survey data will be instrumental in refining future engineering activities, aiming to enhance the interest and engagement of female students across various STEM modules.

7. References

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