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A Comparison Between a Week-Long Electrical and Computer Engineering Summer Camp's Session on Middle School Students' Interests in STEM (Evaluation)

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A Comparison Between a Week-Long Electrical and Computer Engineering Summer Camp's Session on Middle School Students' Interests in STEM (Evaluation)

Abstract: Middle school is a crucial period for students developing interests, forming identities, and exploring career choices. STEM summer programs have demonstrated that these aspects can be effectively influenced by including various hands-on learning activities. Structuring the camps to have interactive, hands-on sessions is vital to aligning students' values and interests within STEM disciplines. Within these summer camps, it is essential to identify which activities significantly increase the students' likelihood of pursuing careers in STEM fields. This study compares two cohorts of electrical and computer engineering (ECE) summer camps to find which camp structure better fosters student interest in STEM fields and disciplines. One camp structure features more activities throughout the day for a shorter period of time, while the second involves longer sessions with fewer activities overall. In the summers of 2023 and 2024, 18 and 19 students, respectively, participated in week-long summer camps covering ECE concepts and practices. Each camp, lasting four to five days, included hands-on activities, tours of ECE laboratories, and a week-long group project where students built circuits using the SparkFun Inventor's Kit. The students worked in groups during the project phase, each with an undergraduate mentor who facilitated and assisted in the various collaborative activities. For both offerings, the middle school students completed validated and reliable pre- and post-surveys adapted from the Student Attitudes Toward STEM (S-STEM) Survey and the Group Work Skills Questionnaire Manual. The S-STEM survey assessed STEM interests, while the Group Work Skills Questionnaire Manual Survey evaluated collaboration. Preliminary results from a Wilcoxon Signed-Rank test indicated positive significance that the 2024 ECE summer camp sessions led to greater enjoyment for campers than the 2023 offering. Daily reflection surveys were also administered to understand the comparison of cohorts and the impact of individual activities students participated in each day. Results were analyzed to identify activities in which each cohort positively improved domains in student interests. This approach provides meaningful insights for developing more inclusive and impactful STEM education interventions, ultimately enhancing the structure and effectiveness of STEM summer camps.

Keywords: Electrical and Computer Engineering, Middle School Summer Camp, STEM education

Introduction

Based on data from the U.S. Bureau of Labor Statistics, the overall demand for engineers is expected to grow at a faster rate than the average for all occupations from 2023 to 2033 [1]. A survey of 90 engineering students at the University of New Haven found that 65% of them had decided to study engineering by the age of 16 or earlier [2]. Another survey with 500 U.S. college students studying STEM reported that 78% of them decided to pursue a career in STEM in high school or earlier and 21% decided in middle school or earlier; 68% female students credited a teacher or a course before going to college sparked their interest in STEM as compared to 51% in male students [3]. Therefore, it is essential to address workforce development early, such as during middle school. A study of 890 middle school students in New Jersey found that those exposed to pre-engineering concepts in their classrooms showed a more positive attitude towards STEM and were more knowledgeable about engineering careers [4].

Consistent engagement with middle school students during regular school hours is challenging to implement due to the existing curriculum's structure. Summer camps provide a perfect opportunity to fill in the gaps. Typical summer camps are usually a week-long event, for which it requires reasonable commitment while offering flexibility to both the participants and the instructional staff. Many universities these days offer STEM summer camps on campus. Campers not only have the opportunity to gain experience in specific topics but also get a taste of college life. For example, MIT’s DynaMIT program offers a one-week camp free of charge for Boston residents [5]. Berkeley’s Girls in Engineering runs a week-long camp for girls from the San Francisco Bay Area [6]. Carnegie Mellon’s Summer Engineering Experience offers a one-week camp on making & engineering [7]. Georgia Tech runs multiple sessions of weekly summer programs for Enrichment and Accelerated Knowledge in STEAM [8]. Studies have shown that week-long summer camps in various formats have increased middle school students’ interest in STEM and improved their attitudes toward STEM careers [9, 10, 11, 12].

Being exceptions to the norm, a few universities also offered longer summer camps for middle school students. For example, Northwestern University runs several three-week-long STEM summer camps in addition to the traditional week-long camps [13]. New York University offers a free three-week-long summer camp for local residents [14]. Last but not least, Johns Hopkins University’s renowned Center for Talented Youth program offers an extensive range of 3-week summer courses in STEM [15].

Camp Inception and Planning

The Grainger College of Engineering has offered summer camps for high school students for the past few decades at the University of Illinois Urbana-Champaign. These summer camps provide various discipline-specific content to participants. Both locals and students from around the country participated in these programs. Shortly before 2020, some departments began offering day camps to middle school students. The Electrical and Computer Engineering (ECE) department began planning a new in-person middle school summer camp with the college outreach office in 2022. The college managed the application process for all engineering summer camps, typically allowing a maximum of 25 students for discipline-specific offerings.

The ECE faculty consulted outreach specialists from other engineering departments who have experience working with middle school students on various topics. The findings from these meetings were that hands-on activities were needed to maximize learning and engagement. The hands-on activities in the ECE summer camp included introductions to electronics, digital logic, music synthesis, optics, and sorting algorithms. In addition, tours and interactive demos cover topics in robotics, antenna, bioengineering, historical museum, and semiconductor fabrication (cleanroom). Within these sessions, there is a mix of hands-on activities, tours, and interactive demonstrations, all facilitated during both morning and afternoon hours. Students partnered with another student at the end of each day to work on an electronics group project under the guidance of one or two undergraduate lab assistants. This project time allowed students to learn about simple circuits and coding using SparkFun Inventor Kits. These kits were reasonably affordable (~ $100/kit) and included easy-to-follow user manuals with activities. Additional social activities, such as bowling and ping pong, were planned after lunch so the students could get to know each other.

Camp schedule

The ECE summer camp in this study offered a well-organized week of activities where middle school students explored the exciting field of ECE through a mix of hands-on activities, tours, and team projects. The schedule balanced a variety of educational and recreational events to keep students engaged and excited about learning.

Some highlights of the camp activities included tours of state-of-the-art facilities, such as the cleanroom and robotics lab, as well as interactive sessions on topics like music synthesis and digital logic. Team projects using Sparkfun Inventor kits also promoted creativity and teamwork. Recreational activities like bowling and museum tours were fun and encouraged community building among campers.

For the 2024 iteration of the camp, there were only four days instead of five due to the observance of Juneteenth. A detailed camp schedule was shown in Table 1 below.

Table 1. Daily camp schedule for the ECE middle school ECE summer camp

Time	Monday (6/17)	Tuesday (6/18)	Thursday (6/20)	Friday (6/21)
Morning	Welcome speech	Cleanroom Tour	Intro. to Bioengineering	Virtual Reality
	Tour of ECE Department	Antenna Lab Tour	Intro. to Music Synthesis	Robotics Lab
	Icebreaker Activities & Jeopardy!	Optical Projector & Oracle Sort	Bowling	Historical Museum
Noon	Lunch	Lunch	Lunch	Lunch
Afternoon	Intro. to Electronics	Intro. to Digital Logic	Probabilities	Preparation for Team Presentation
	Team Formation & Team Project	Team Project	Team Project	Team Presentation & Camp Closing Celebration

Each day was structured similarly (9:00 AM - 5:00 PM), where students would participate in various activities to learn, grow their teamwork, and have fun with various ECE activities. The camp leaders met and greeted students and parents every morning in front of the building. On the first day of the program, a camp overview was presented to the students and parents. The camp was structured daily with check-ins, three morning activities, lunch, one afternoon activity, and followed by group project time. The lab tours were usually held in morning sessions, while more collaborative, hands-on activities took place in the afternoons. At the end of each day, the middle school students and undergraduate lab assistants gathered for daily surveys and then focused on the SparkFun Inventor Kits team projects. This project lasted the whole week, where groups completed each lesson at their own pace. At the end of the summer camp, all students and their families were invited to attend a closing ceremony. Each group presented their group projects to family members in the audience on their group project and favorite activities. After all the presentations, swag bags and certificates were given out to all the campers. Students and family members appreciated the camp leaders and inquired about future summer programs within the university.

Participants

18 to 25 campers were expected to participate in 15 weekly activities. 2024's iteration of the ECE summer camp had 19 participants, one more than the 2023 implementation. Two ECE faculty members led this summer camp and served as the same co-leaders as in the 2023 offering. The faculty members also recruited two Ph.D. students in education to facilitate. One Ph.D. student who helped during the 2023 camp was also conducting further research on the interaction of the 2024 camp offering. The faculty hired another Ph.D. to primarily supervise the middle school students. Seven faculty, two staff, and seven graduate students taught the various ECE sessions.

13 undergraduate students were lab assistants for the group projects. One camper from the 2023 iteration also volunteered to help with the camp activities.

Fourteen students consented and participated in the ECE summer camp; 12 were male, and two were female. Seven students were 12 years old or younger (referred to as <12 for the rest of the paper), and another seven were 13 years old or older (referred to as 13+ for the rest of the paper). An additional question about prior STEM experiences was asked to all participants, where five of the fourteen had prior experience specifically with middle school robotics.

Methods

Data Collection

The data for this study was collected from the middle school (MS) students who provided consent to participate in the research. Several surveys were employed for this evaluation study. The first survey is a modified version of the Student Attitudes toward STEM (Science, Technology, Engineering, and Mathematics) Survey, initially developed by The Friday Institute for Educational Innovation. This modified survey has been shown to be valid and reliable [16]. This fact ensures appropriateness for assessing middle school students' attitudes and perceptions toward STEM fields.

The original survey consists of 37 questions. Each question is rated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), to help comprehend students' attitudes towards STEM topics. Specifically, the survey included eight statements related to mathematics, nine related to science, nine to engineering and technology, and eleven to 21st-century learning skills. The terminology of "21st-century skills" encompasses a broad set of competencies, including knowledge, skills, work habits, and character traits, that educators, reformers, academicians, and employers consider essential for success in today's society. The research team added another section from the STEM survey to gather more background information on the students' current and future STEM education experiences. The last section was broken down into three parts: current class expectations (4 questions), future STEM interests (3 questions), and professional connections (5 questions). For the last sections, the students were given a scale with expectations ranging from one to three (Not Very Well to Very Well) to answer the questions. The professional connections consisted of a scale with options of "yes", "no", and "not sure". Another survey component investigated the collaborative learning of middle school students in STEM. Eight additional questions from a group work skills questionnaire were added after the section on 21st-century learning [17]. This section helped the comprehension of team dynamics and how these collaborations impact middle school students during a STEM activity. With all these additions, the survey contained a total of 57 items.

In addition to the altered Student Attitudes Toward STEM Survey, daily surveys were administered to participating middle school students throughout the four-day summer camp. The research team utilized these daily surveys to capture instant feedback and reactions to sessions throughout the four days. Key questions included rating their overall experience, identifying the most enjoyable, challenging, and valuable activities of the day, and pinpointing activities that particularly sparked their interest in engineering or encouraged further exploration. Seven questions were asked, as listed in Table 2.

Table 2. Questions included in the daily survey

Questions	
1	On a scale of 1 to 5, please rate your overall experience at the engineering camp today.
2	Which specific activity or activities from the engineering camp did you find most enjoyable today? Please select all that apply.
3	Which activity challenged you the most during the camp? Please select one.
4	Which activity from the engineering camp do you think you would like to explore further in the future? Please select one.
5	Did any particular activity or activities spark your interest in engineering? If yes, please specify which one(s) and briefly explain why.
6	What aspect of the engineering camp did you find most valuable or impactful? Please explain briefly.
7	Is there anything else you would like to share about your experience at the engineering camp or your interest in engineering?

Analysis Procedure

Over the four-day middle school ECE summer camp, the student participants completed a pre- and post-survey of 57 valid and reliable questions. This survey aims to assess the impact of students' summer camp experiences on their STEM education. A researcher organized and conducted a statistical analysis using the SPSS software. The pre- and post-survey responses were used to determine the impact of the camp on the students. The normality of the data was checked. Since the data was non-normal, the researcher conducted Wilcoxon Signed-Rank tests to assess the significant impact from the pre- to post-tests. Additionally, the researcher calculated the effect size (r). The variables of gender, age, and prior STEM experiences were also collected in the surveys. During the analysis, the researcher separated the students into groups based on gender (male/female), age (<12/13+), and prior STEM experience. Wilcoxon Signed-Rank tests were also employed to determine if there is an effect on the students' STEM education and careers based on gender, age, or prior STEM experience.

Due to technical difficulties in the 2023 version, the pre- and post-surveys of 2024 included more questions in the group work and professional connections interest sections. Due to this inconsistency, the research team omitted the group work section and one question on professional connections between the two years. Between the 2023 and 2024 iterations, some sessions were rerun with revisions based on feedback from 2023, some sessions were excluded (due to reduced camp days), and some were new.

Camp Differences

The differences between the STEM summer camps consist of the 2024 duration being a four-day camp, compared to the 2023 five-day camp. Findings from the 2023 iteration of the summer camp can be found in [18]. Five sessions were removed from the prior 2023 summer camp. The Probabilities and Antenna Lab Tour were added to the 2024 schedule. Different instructors led the digital logic program, facilitating new activities in the Introduction to Electronics activity. The modifications allowed more time to engage in STEM concepts through hands-on activities, rather than worrying about traveling to the next session. While the camp duration varied from summer to summer, the overall goal remained consistent: to provide enriching STEM experiences for the campers. Both iterations intensely focused on interactive learning, mentorship opportunities, and collaborative learning to promote enthusiasm for STEM fields.

Results

Impact of the summer camp on the students

A Wilcoxon Signed-Rank test was used on the pre- and post-test results to evaluate the impact of the 2024 summer camp on the students' STEM education knowledge. The test results in Table 3 indicated a significant improvement in students' competencies in mathematics, sciences, engineering and technology, 21st-century learning, and group work.

Table 3. Wilcoxon Signed-Rank Test results (*N* = 14)

Domains	Pre-test Mean (SD)	Post-test Mean (SD)	Wilcoxon Signed-Rank Test		
			Z	***p***	***r***
Mathematics	3.13 (0.25)	3.31 (0.27)	-2.70	0.02*	-0.19
Science	3.38 (0.59)	3.71 (0.58)	-3.10	<0.01*	-0.83
Engineering & Technology	4.10 (0.41)	4.29 (0.45)	-2.34	0.02*	-0.63
21st-Century Learning	4.05 (0.39)	4.33 (0.47)	-2.14	0.03*	-0.57
Group Work	4.12 (0.43)	4.44 (0.51)	-2.46	0.01*	-0.66
Current Class Expectations	2.61 (0.42)	2.45 (0.38)	-1.63	0.10	-0.43
Future STEM Interests	2.45 (0.34)	2.52 (0.39)	-0.59	0.59	-0.16
Professional Connections	2.33 (0.40)	2.30 (0.46)	-0.58	0.57	-0.15

*Significant, $p < 0.05$

A Wilcoxon Signed-Rank test was conducted on the additional variable of gender, as shown in Table 4. Twelve male and two female students consented.

Table 4. Wilcoxon Signed-Rank Test results between male and female (N_M = 12; N_F = 2)

Domains	Gender	Pre-test Mean (SD)	Post-test Mean (SD)	Wilcoxon Signed-Rank Test		
				Z	***p***	***r***
Mathematics	M	3.11 (0.26)	3.29 (0.28)	-2.69	<0.01*	-0.78
	F	3.31 (0.09)	3.31 (0.09)	0.00	1.00	0.00
Science	M	3.38 (0.65)	3.75 (0.63)	-2.84	<0.01*	-0.82
	F	4.13 (0.53)	4.56 (0.80)	-1.34	0.18	-0.95
Engineering & Technology	M	4.07 (0.44)	4.24 (0.46)	-1.85	0.07	-0.63
	F	4.75 (0.00)	4.67 (0.00)	-1.41	0.16	-1.00
21st-Century Learning	M	4.07 (0.42)	4.29 (0.47)	-1.61	0.11	-0.46
	F	3.73 (0.26)	4.64 (0.51)	-1.34	0.18	-0.95
Group Work	M	4.17 (0.45)	4.43 (0.51)	-2.09	0.04*	-0.60
	F	4.25 (0.47)	4.39 (0.08)	-1.34	0.18	-0.95
Current Class Expectations	M	2.54 (0.42)	2.35 (0.33)	-1.29	0.20	-0.37
	F	3.00 (0.00)	2.50 (0.71)	-1.00	0.32	-0.71
Future STEM Interests	M	2.42 (0.35)	2.47 (0.39)	-0.35	0.73	-0.10
	F	2.83 (0.24)	3.00 (0.00)	0.00	1.00	-0.00
Professional Connections	M	2.35 (0.34)	2.35 (0.40)	-0.11	0.91	-0.03
	F	2.80 (0.00)	2.50 (0.14)	-1.34	0.18	-0.95

*Significant, $p < 0.05$

These test results indicate that male students were significantly impacted in mathematics, science, and group work domains. The female students had no significant differences between the start and end of the summer camp. No other domains were significantly impacted with the variable of gender in mind.

With age considered, students were separated into two groups: those 12 and younger (<12) and those 13 and older (13+). Students who are 12 usually go into sixth grade. Students who are 13 or older are entering seventh or eighth grade. At the higher grade level, more complex topics can be taught. Another Wilcoxon Signed-Rank test was run to determine how the age variable affects students' growth in STEM education from the 2024 iteration of the summer camp, as shown in Table 5. Students in the 13+ category showed significant improvements in their mathematics, science, engineering, and technology, as well as group work domains. For the <12 students, there is no statistical indication of significant differences between the start and end of the summer camp in most domains, except in science. No other areas showed significant values either.

Table 5. Wilcoxon Signed-Rank Test results <12 and 13+ year old ($N_{<12}$ = 7; N_{13+} = 7)

Domains	Age	Pre-test Mean (SD)	Post-test Mean (SD)	Wilcoxon Signed-Rank Test		
				Z	***p***	***r***
Mathematics	<12	3.16 (0.33)	3.32 (0.30)	-1.73	0.08	-0.65
	13+	3.11 (0.15)	3.30 (0.26)	-2.06	0.04*	-0.78
Science	<12	3.65 (0.56)	3.95 (0.58)	-2.05	0.04*	-0.77
	13+	3.11 (0.53)	3.49 (0.52)	-2.38	0.02*	-0.90
Engineering & Technology	<12	4.17 (0.42)	4.33 (0.50)	-1.51	0.13	-0.57
	13+	4.03 (0.43)	4.25 (0.43)	-2.00	0.05*	-0.76
21st-Century Learning	<12	3.92 (0.37)	4.32 (0.49)	-1.57	0.12	-0.59
	13+	4.17 (0.40)	4.34 (0.50)	-1.88	0.06	-0.71
Group Work	<12	4.16 (0.39)	4.48 (0.55)	-1.36	0.17	-0.51
	13+	4.07 (0.49)	4.39 (0.51)	-2.12	0.03*	-0.80
Current Class Expectations	<12	2.75 (0.29)	2.46 (0.37)	-1.60	0.11	-0.61
	13+	2.46 (0.51)	2.43 (0.43)	-0.45	0.66	-0.17
Future STEM Interests	<12	2.67 (0.19)	2.67 (0.43)	0.00	1.00	0.00
	13+	2.24 (0.32)	2.38 (0.30)	-0.82	0.41	-0.31
Professional Connections	<12	2.51 (0.41)	2.37 (0.41)	-1.63	0.10	-0.62
	13+	2.14 (0.30)	2.23 (0.52)	-0.71	0.48	-0.27

*Significant, $p < 0.05$

An additional variable was added to the survey to collect students' prior experiences in STEM fields. These open-ended questions provided further insight into the middle school students' backgrounds in STEM fields. For this test, experiences were coded as "1," and no experience was coded as "0" in the document. Nine students had no STEM experience, and five had prior experiences, particularly in middle school robotics. Another Wilcoxon Signed-Rank test was used to determine the significance of each category, as shown in Table 6. Students with no prior experience in STEM showed significant differences in mathematics, science, engineering, and technology skills. At the same time, students with previous experience indicated growth only within the science domain. No other domains in this category were statistically significant.

Table 6. Wilcoxon Signed-Rank Test results prior STEM Experience (N_0 = 9; N_1 = 5)

Domains	Prior Exp	Pre-test Mean (SD)	Post-test Mean (SD)	Wilcoxon Signed-Rank Test		
				Z	***p***	***r***
Mathematics	0	3.11 (0.29)	3.38 (0.31)	-2.54	0.01*	-0.85
	1	3.18 (0.17)	3.20 (0.14)	-0.58	0.56	-0.26
Science	0	3.44 (0.53)	3.77 (0.52)	-2.38	0.02*	-0.79
	1	3.27 (0.75)	3.64 (0.73)	-2.04	0.04*	-0.91
Engineering & Technology	0	4.12 (0.45)	4.36 (0.43)	-2.33	0.02*	-0.78
	1	4.07 (0.39)	4.18 (0.50)	-1.09	0.28	-0.49
21st-Century Learning	0	4.05 (0.38)	4.29 (0.50)	-1.55	0.12	-0.52
	1	4.04 (0.45)	4.40 (0.46)	-1.29	0.20	-0.58
Group Work	0	4.07 (0.44)	4.31 (0.53)	-1.73	0.08	-0.58
	1	4.20 (0.46)	4.68 (0.40)	-1.76	0.08	-0.79
Current Class Expectations	0	2.47 (0.42)	2.42 (0.35)	-0.82	0.41	-0.27
	1	2.85 (0.34)	2.50 (0.47)	-1.34	0.18	-0.60
Future STEM Interests	0	2.37 (0.35)	2.41 (0.36)	-0.11	0.91	-0.04
	1	2.60 (0.28)	2.73 (0.37)	-1.41	0.16	-0.63
Professional Connections	0	2.29 (0.40)	2.24 (0.48)	-0.71	0.48	-0.24
	1	2.40 (0.42)	2.40 (0.45)	0.00	1.00	0.00

*Significant, $p < 0.05$

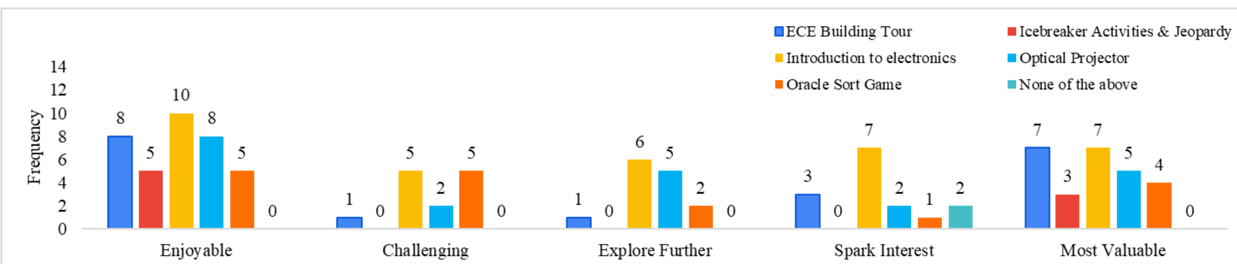
At the end of each summer camp day, students completed a daily survey that consisted of questions evaluating and reflecting on the day's activities. On a five-point Likert scale, students rated the overall experience for each day of the summer camp, assessing the day's activities. These ratings were usually in the four- and five-ranges. One student was in the middle daily with a "3" value.

The 2024 iteration of the summer camp lasted four days, each featuring hands-on activities and learning experiences to engage and educate middle school students. On the first day, the activities illustrated in Figure 1a included a tour of the ECE building, an icebreaker activity, a Jeopardy game, an introduction to electronics, a demonstration with an optical projector, and an oracle sort game. Out of all these sessions, students enjoyed the session on introduction to electronics the most. Other enjoyable activities followed the building tour and optical projector sessions closely. Students found that the introduction to electronics and the Oracle sort game to be the most challenging sessions that day. Consistent with the prior questions, students want to explore electronics further. They also found that this session sparked their interest and was the most valuable of the day. Some students also found the building tour valuable.

For the second day, as depicted in Figure 1b, the students participated in a cleanroom tour, an antenna lab tour, bowling, and an introduction to digital logic. Compared to the other sessions, the students enjoyed bowling, and the cleanroom tour the most. The introduction to digital logic session was the most challenging session. Similarly, the introduction to digital logic also sparked interest, was found to be the most valuable, and made students want to explore it further compared to all other sessions.

The third day of the camp was filled with sessions on bioengineering, virtual reality (VR), introduction to music synthesis, a historical museum visit, and a probabilities session, illustrated in Figure 1c. The students found that the VR and probabilities activities were the most enjoyable, while they found the music synthesis to be the most challenging. Students wanted to explore the probabilities and VR activities further. Again, the VR session sparked the most interest, while the probabilities and bioengineering sessions were close behind. Lastly, students found the historical museum to be most valuable, with the VR and probabilities sessions closely behind again.

On the last day of the camp, the students participated in bioengineering, VR, and a robotics lab visit, as shown in Figure 1d. The students found the robotics lab visit to be the most enjoyable. Students who attended the bioengineering activity discovered it to be the most challenging. As the robotics lab was the most satisfying, students wanted to explore it further, which sparked interest in future endeavors, and they viewed it as the most valuable.



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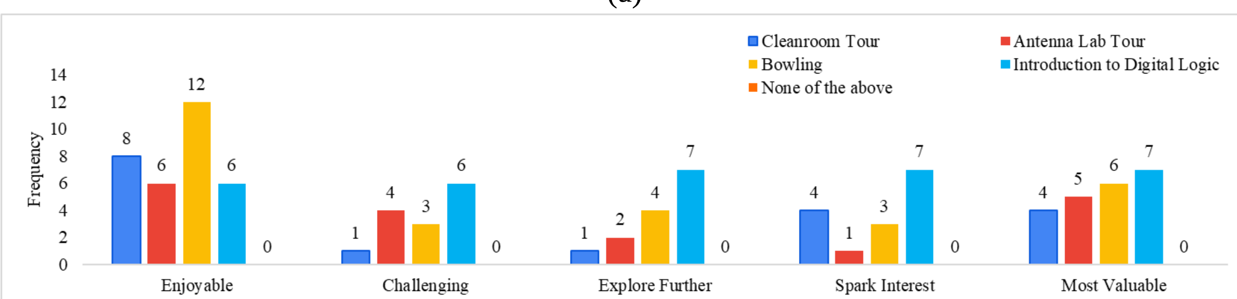

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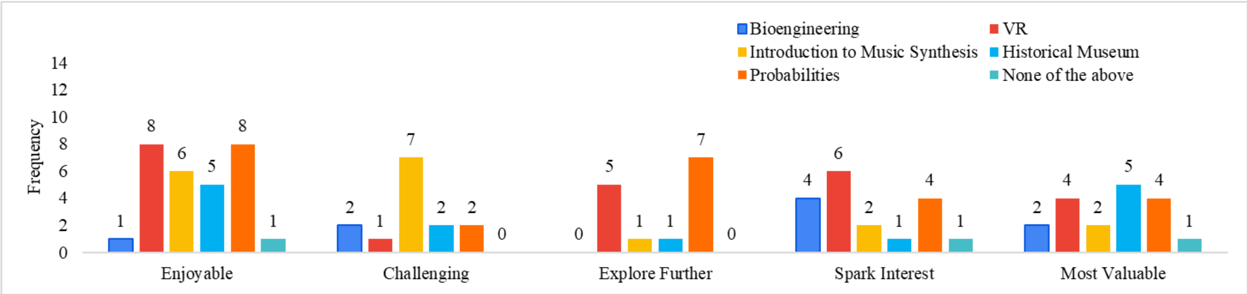

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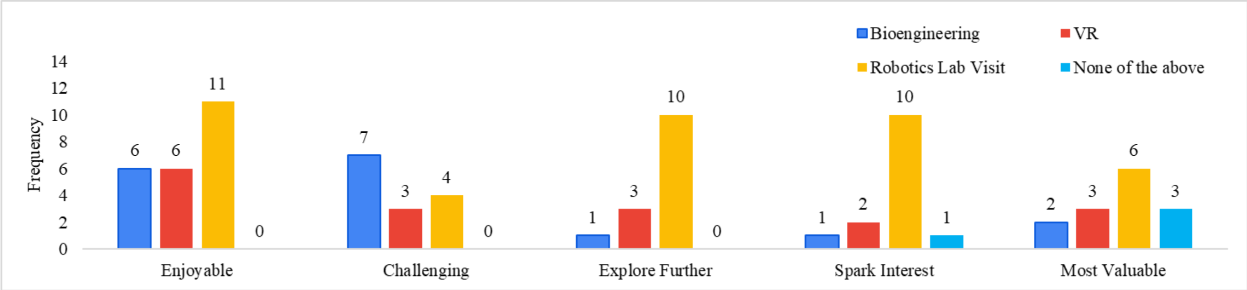

(d)

Figure 1: Survey responses by participants for each day

Takeaways from Students

Students could add comments to their answers at the end of the daily surveys. They also provided additional comments on the last day of camp in their group presentations.

On the last day, a student commented on their group projects, expressing appreciation for their undergraduate mentor.

"My mentor for the project was very kind and helped us learn a lot."

At the final presentations to the family members on their group projects and overall takeaways from the summer camp, one group said,

"Overall, our experience at camp was pleasant, entertaining, and educational. We are happy that we were able to attend."

These additional comments from these students throughout the four-day summer camp provide further insight into their growth and development.

Discussions

This study evaluates the impact of a week-long middle school summer camp on students' perceptions of STEM fields in its second iteration. This study found significant results on the impact of middle schoolers' STEM perceptions, which align closely with the literature of [19], [20], [21]. As middle school is a time for shaping interests and trajectories, the results indicate that students gained interest in furthering their exposure to STEM topics after this summer camp. Improvements in all STEM fields, 21st-century learning, and group work have helped to understand middle school students' interests and educational aspirations.

The pre- and post-surveys illustrated a significant difference in students' mathematics, science, engineering and technology, 21st-century learning, and group work skills. Students enjoyed each activity that was held each day. In their open answers, many students provided details that they would extend this STEM concept further in the future. As one student explicitly talking about the introduction to electronics said, *“The introduction to electronics because learning that was fun, and I want to learn more about that because it was very simple, but there is a lot of room to expand on it.”* The sessions in the 2024 iteration allowed students to dive deeper into a topic since there were fewer activities but more time devoted to each session.

Comparison of 2023 vs. 2024 structures

A comparison between this summer camp's 2023 and 2024 iterations illustrates differences. As stated before, there were more sessions in the 2023 camp, but less time was devoted. This crucial change in the middle school camp's structure could have resulted in differences between the pre- and post-test results. Students in the 2023 summer camp indicated a significant difference in 21st-century learning, group work, current class expectations, and future STEM interests. In 2024’s iteration, there were significant differences in mathematics, science, engineering and technology, 21st-century learning, and group work skills. The differences in 2024 may be attributed to more mathematical and scientific connections during activities. The differences between current class expectations and future STEM interests may be derived from having fewer site visits. These experiences have been shown to improve student comprehension and connections to STEM disciplines [22].

Another main difference between the two offerings was the duration. Differences in STEM learning outcomes could have been affected from 2023’s five-day camp to 2024’s four-day camp. Surprisingly, the outcomes of the group work portion of the camp were not impacted. Students in the 2024 camp may not have completed as many lessons with the SparkFun Inventor’s Kit, but they had similar learning outcomes and enjoyed participating in the lesson activities.

During the debrief after the 2023 offering, some sessions were found to be too difficult for middle school students to comprehend. For 2024, those complex activities were removed, and more sessions that deeply engage young learners were incorporated. For example, there were changes in the format of the digital logic session and the addition of a probability session (dice game). Students in 2023 found the digital logic session more complex [18]. With this modification, students who participated in 2024, as represented in Figure 1c, found it enjoyable and less complicated.

Even with these modifications, students still find engineering components, such as digital logic and electronic sessions, valuable but challenging. To balance rigor and engagement, future implementations for the camp can include a scaffolding approach where concepts build up each other to introduce foundational knowledge before progressing to more complex topics. Having more structured guidance from mentors can improve and limit frustrations. Providing real-world examples and connecting to industry can also indicate realistic approaches to challenging concepts.

With hands-on academic activities, lab visits, structured icebreakers, and social activities like bowling and Jeopardy, these elements played a crucial role in creating a supportive learning environment for the campers. These activities helped students feel more comfortable engaging with their peers and mentors. This approach can create more engaging experiences throughout the various activities. Research indicates that providing opportunities for students to interact socially enhances idea generation and engagement with diverse perspectives, positively impacting overall learning outcomes in STEM programs [23].

2023 vs. 2024 Gender Comparison

When comparing 2023 and 2024 student outcomes, keeping the gender variable in mind, each group had some differences. Male students in the 2023 iteration had significant changes in their engineering, technology, and group work domains. Meanwhile, the 2024 male population showed significant growth in mathematics, science, and group work skills. An additional Wilcoxon Signed-Rank test indicated a significant difference in male students between the 2023 and 2024 camps in the categories of current class expectations ($\mathrm{p} < .01$) and future STEM interests ($\mathrm{p} < .01$). These findings can be attributed to changes in activities and sessions. While some of 2023's sessions focused on engineering and technology, the 2024 schedule had fewer sessions.

A comparison of female middle school students' outcomes was not conducted because there was only a population of two for the 2024 cohort. A comparison with all consenting students indicated differences between the 2023 and 2024 groups in the science ($p = .04$), current class expectations ($p < .01$), and future STEM interests ($p < .01$) domains. The 2024 iteration focused on integrating mathematical and scientific concepts into hands-on activities and real-world problem-solving. This modification might have led to a stronger connection between students' learning experiences with math and science compared to STEM careers and future STEM coursework.

2023 vs. 2024 Age Comparison

Students of various ages participated in the middle school STEM summer camp. The majority of the students were between the ages of 12 and 13. Considering this variable, the student age outcomes for 2023 and 2024 were compared. Students in the 2023 cohort who were 12 years old only grew in group work, while those who were 13 or older noticed significant differences in current class expectations and future STEM interests. Meanwhile, in the 2024 cohort, the <12 students only noticed substantial differences in the science domain, while the 13+ students had skill development in their science, mathematics, engineering and technology, and group work domains. These differences can be attributed to the session activities and structures. Also, the 2024 cohort had a wider range of ages, which could have contributed to these differences.

Limitations

The 2024 middle school summer camp faced some limitations that may influence the outcomes and their generalizability:

- **Reduction of group work:** As shown in the survey analysis, reducing the daily group project from 4.5 days in the 2023 camp to 3.5 days in the 2024 camp did not significantly affect the Group Work category outcomes. However, this reduction may influence the effectiveness of collaborative learning experiences. Additional qualitative feedback from students could help in understanding whether the allocated time for group work is sufficient.
- **Activity Adjustments:** Some sessions were adjusted because the camp was reduced to 4 days in the 2024 version, and also based on student feedback. For example, the solar car lab visit was removed due to the lack of air conditioning on hot summer days. Also, the introduction to digital logic session was modified due to a new instructor. To enhance student engagement and add more hands-on activities, the probability session was added, where students explored many dice games and simple coding on probability.
- **Sample size:** Overall, the survey sample size is small. There were 19 participants in the 2024 camp and 18 participants in the 2023 camp. 14 and 15 students consented to participate in the survey at these two camps, respectively. Most of the participants were from local middle schools, which may not be representative of the broader population.
- **Skewed gender ratio**: Among all students who applied for the program during the 2024 version of this middle school summer camp, 17% identified themselves as female students. And only two female students participated in the survey, so the results cannot be thoroughly compared to those of their male counterparts.
- **Financial barrier**: The $600 camp fee for the week may deter applicants from lower-income families, despite the availability of scholarships. 32% of the participants were from private schools, while 68% came from public schools. The results may be biased toward middle- and upper-income households due to this financial barrier.

As indicated above, the limitation of having only two identifying female students significantly impacts the comparison between the outcomes of the 2023 and 2024 ECE summer camps. This may be a one-year occurrence, as the 2023 cohort had more female participants than males [18]. Future iterations of the camp will continue to monitor gender representation and explore strategies to encourage broader participation.

The college outreach office oversees all summer camp offerings, including the recruitment and application review processes. Therefore, it is often not possible for the camp leaders to overcome some of the limitations outlined above, such as gender ratio and financial barriers. However, the ECE department could advertise this summer camp offering on their website and provide funding for additional scholarships.

Recommendations to others

Based on the findings from the 2023 and 2024 ECE summer camps, the following recommendations for designing and implementing STEM learning programs are listed below:

- **Longer, in-depth sessions:** Longer, more immersive activities allow students to engage deeply with STEM topics, rather than multiple shorter activities that rush them.
- **Daily reflection and feedback**: Collecting campers' feedback through short-daily surveys provides immediate insight into the most engaging or valuable activities.
- **Broadening Participation**: Reducing financial barriers and providing scholarship funding can help students participate in the camp.
- **Group collaboration and mentorship**: Encouraging structured teamwork with undergraduate mentors can create a community where multiple perspectives can be shared to develop multiple perspectives. Ensure groups have sufficient time to learn and reinforce each other's knowledge.
- **Fun social activities**: Allowing campers to connect with their peers and mentors in a relaxed environment to build rapport.
- **Connecting activities to real-world applications and future careers**: Incorporate how STEM concepts apply to real-world scenarios through lab tours, problem-based activities, and industry speakers to increase students' interest in STEM careers.
- **Iterate on evaluations**: Modify camp structures and activities based on the camper's feedback. If activities and sessions are meaningful to students, do not be afraid to keep the same activity.

Conclusions & Future Work

The study evaluates the second iteration and the impact of a week-long middle school summer camp on students' STEM perceptions. In mathematics, science, engineering, and technology, 21st-century learning, and group work skills were enhanced. For gender, there was specific growth in mathematics, science, and group work in the male group; the female group was excluded from analysis due to the limited sample size. Regarding age, 13+ students showed a significant increase in mathematics, science, engineering and technology, and group work. Students without prior STEM experiences grew in their mathematics, science, and engineering and technology skills, while students with prior experiences grew only in the science domain. The addition of implementing the daily surveys provided vital information, offering insight into which activities were most engaging, challenging, highlighted value, sparked interest, and which activities students wanted to explore further. The data collected during the second iteration of the summer camp is instrumental in refining the next iteration of the camp. Although there are limitations, including a small sample size and financial barriers, our research enhances the understanding of effective strategies in informal STEM education. It highlights the importance of early and engaging exposure to STEM fields for cultivating the next generation of STEM professionals. Our research contributes to an understanding of iterative summer camp sessions to meet the needs of middle school students during a week-long STEM summer camp. This research contributes to informal STEM education and explains why engaging middle school students in developing into future STEM professionals is essential.

Future work aims to continue collecting and modifying camp iterations to benefit the middle school student participants. Through this longitudinal study, the results from this paper will encourage modifications to the camp structure and sessions. Future work will also enable faculty, staff, and graduate and undergraduate students to discuss career options in engineering during these sessions. This approach will provide valuable insights for connecting session activities to STEM careers, contributing to the development of the next generation of STEM professionals.

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