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Interdisciplinary Engineering Education in a Middle School Computer Science Camp

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1 Introduction

Engineering fields continue to fall short of proportionally representing people who identify as women, Hispanic and/or Black. In 2024, women made up 42% of the global workforce, but only comprised 28.2% of the science, technology, engineering, and mathematics (STEM) sector [18]. Similarly, in 2021 Hispanic individuals held 17% of jobs in the US and only 8% of US STEM jobs. In the same year, Black individuals represented 11% of the US workforce and just 9% of the US STEM sector [19]. It is likely that varied approaches are needed to solve this persisting problem.

One promising avenue for broadening participation in engineering is by expanding students' perceptions of the the applicability of engineering for social good [3, 9]. In order to help students see themselves solving today's most pressing and complex societal issues, engineering education needs to teach students to connect knowledge across academic disciplines [12]. Thus, the growing area of Interdisciplinary Engineering Education (IEE) aims to show students how to approach socio-technical problems at the intersections of typical fields of study [22]. In this paper, we build on this body of work.

We explored middle school students' perceptions of and experiences with an IEE curriculum. Specifically, we evaluated an interdisciplinary curriculum combining computing education with non-STEM (i.e., arts, humanities, and social sciences) fields. This "computing+X" curriculum [7, 8] exposes students to the intersections of computing and subjects such as advertising and linguistics. It intends to encourage students to connect their personal passions and goals with computing while recognizing how a career in computing could allow them to benefit society. Previously, high school students who took the computing+X course reported that their interest in computing increased, and that the course gave them a better understanding of how computing broadly impacts society.

We further knowledge on this topic by trying to answer the following question: How can the existing computing+X curriculum be modified to engage middle school students in an informal educational setting? We present our implementation of the computing+X curriculum with rising 8th and 9th grade students during two iterations of a week-long engineering summer camp. We offer two summer camps, one for girls and one for students of all genders. Two cohorts of twenty students attended the camps.

This project is a collaboration between a team of computer science researchers from both R1 and R2 universities, who developed the curriculum, and a team from a Mathematics and Science Academy, where the camps were held. The Mathematics and Science Academy offers education for students in grades 10-12 from a Midwestern state and regularly offers summer programming to engage younger students. The CS+X course material was simplified to fit a condensed timeline and a younger audience. Over the camp period, students learned basic programming skills and concepts via a CS+Linguistics Python project. Students also learned and analyzed the ways computing has enhanced non-STEM disciplines, such as anthropology, music, and agriculture.

We evaluated the students' experience and their attitudes towards computing with a pre- and post- survey. The results from this survey showed that the students felt positively about the experience and computing in general. We offer reflections from the summer camp instructors on how they modified the materials to suit their teaching styles, the informal learning setting, and the population of middle school students.

Our goal with presenting this work is to help envision a pathway in engineering education that uses an interdisciplinary approach to engage students from K-12, into higher education, and beyond. Specifically, our evaluation is guided by the following questions:

- Q1: How does an IEE-focused summer camp impact middle school students (1) CS confidence, (2) CS interest, (3) sense of belonging in CS, (4) perception of encouragement in CS, and (5) perception of usefulness of CS?
- Q2: How do middle school students perceive the affordances of an IEE-focused project in terms of creativity, engagement, persistence, novelty, and challenge?

2 Background

Van den Beemt et al. [22] provide a comprehensive overview of how IEE is conceptualized, implemented, and facilitated in higher engineering education. We refer readers to their analysis for a brief introduction to IEE research. Importantly, they show that IEE literature heavily centers on undergraduate students. Thus, the literature we present here is the most relevant known findings to our current study. By focusing on a middle school population, our work helps fill the gap in our collective knowledge.

A literature review of 68 IEE articles published between 2000 and 2021 found that students' beliefs and attitudes were the most prevalently studied outcome with 42% of the articles including such a measure. In sum, the literature shows that IEE could increase students' positivity towards engineering fields. Here we summarize three recent studies (i.e., published in 2024 or later) to illustrate some of the latest findings about student experiences with IEE.

A study conducted with participants from a 100-level information literacy class at a mid-Atlantic university (treatment, n = 137; comparison, n = 112) showed a positive student perception of IEE [14]. Students in the treatment group did a course project integrating the disciplines of mechanical engineering and education. In the control group, students worked on an engineering problem using the engineering design process. After collecting data from numerous semesters, they reported the treatment group had a greater expectation of quality, level of satisfaction, and degree of task commitment.

In another study, researchers interviewed undergraduate students engaged in IEE research [15]. Their participants liked having the opportunity to learn about methodological approaches from other disciplines and believed that the work they produced benefited from the integration of knowledge from multiple domains. They also noted that the interdisciplinary aspect of the research had a humanizing effect on their work. Students with a minoritized social identity in STEM[1] shared that the experience helped develop their identity as a scholar.

As a third example, researchers learned from eight interviews with faculty members involved in an interdisciplinary engineering program at a European university. Their participants believed that IEE helps students build a skillset that is both broad and socially relevant [10]. At the same time, they identified challenges in student motivation stemming from a belief that knowledge outside their field of major is less relevant. Faculty members shared that through conversations with students they may have increased their motivation.

The impact of middle school outreach programs on students' persistence in engineering appears to be positive. Across many years of cohorts, researchers found that a two-week engineering camp for middle school girls resulted in higher applications, acceptance, and attendance to a university at which most students major in a STEM field [2]. The curricular approach to this camp included hands-on learning, service learning, women role models, and an emphasis on collaboration and social context of engineering problems. It is generally understood that mechanism by which these programs impact students is through their attitudes towards engineering.

In this study, we focus on five attitude dimensions: confidence, interest, sense of belonging, usefulness, and encouragement. It has been found that students' interest in engineering at the K-12 level predicts if they will pursue an engineering major and career [1, 6]. Middle school students in informal learning experiences have reported an increased interest in engineering after attending a week-long camp with "hands-on activities, tours of different laboratories in electrical computer engineering disciplines, and a group project that spanned the whole week where students built circuits using the SparkFun Inventor's kit" [11]. Sense of belonging and confidence are also attitudes that seem to be increased by informal engineering experiences for middle school students. In one afterschool program that guided students to "create a micro air-quality sensor that would allow their community to have a better understanding of their local air quality", students' described positive impacts on their confidence and sense of belonging [13].

It appears that neither encouragement nor usefulness have been explicitly measured in terms of middle school students informal learning experiences outcomes, both attitudes have guided work in this area. One camp, running for over 25 years, centers the goal of encouraging young women to pursue engineering [16]. They utilize a variety of research-backed best practices at their camp including women mentors and experts, team-building activities, group projects, residential experience, and tours of local industry. Seventy-percent of participants across ten

[1]Although this term is not defined in the original study, we believe it refers to people who identify as women, Black, Hispanic, Native and/or disabled

years reported that the program opened new opportunities for them. Another engineering summer camp for middle school students, part of a larger initiative to improve engineering education, emphasizes project-based learning in their curricular approach [5]. The reason is to convey the usefulness of engineering, as "PBL experiences enable students to make connections between what they are learning and how it can be used." At this camp students "design candy airplanes, engineer the best popcorn, design products that use slime, and formulate the best film canister rocket propellant."

Our approach differs from past work in that our camp's curriculum is based on understanding the benefits of IEE, and thus our study extends knowledge on different paths by which students' attitudes towards engineering may be improved.

3 Curriculum

We used the IEE curriculum created by Isenegger et al. [7][2]. The intended outcomes of this curriculum largely overlapped with our aims of positively increasing students attitudes towards computing. The curriculum was intentionally designed to be both modular and flexible so that it can meet the needs of various learning environments. The curriculum integrates computing with linguistics, anthropology, advertising, agriculture, music, and philosophy. All units include readings, lectures, and videos to pique students' interest in the topic. Discussion questions are also presented to encourage students to make connections and think critically about the material. The music, anthropology, and linguistics units include Python coding projects that require no previous programming experience. Students learn how create an original musical composition, visualize social science data, and build a silly sentence and poem generator.

Originally developed for a high school "CS+X" (i.e., interdisciplinary computer science) elective course, parts of the curriculum were previously implemented in both advanced placement computer science and a high school social science elective course [8]. CS students reported that the curriculum taught them the new CS skills and that they were confident they could further develop them with more practice. Non-CS students who completed parts of the curriculum were interested in using CS in other fields like psychology and medicine. When asked to define CS, students emphasized the importance of problem solving in both CS and non-CS classes alike. This may show that the curriculum can expand students perceptions of CS beyond stereotypical responses such as "the study of computers". Based on the successful results of bringing the curriculum to different populations of students, we hypothesized the curriculum could be effectively reworked for an informal learning environment for middle school students.

3.1 Goals and Design Principles

The goal of the curriculum is to increase students' positive attitudes towards computing by introducing computing and its applications in a relatable and exciting way. To do so, the

[2]While we briefly describe the curriculum here, we direct readers to the work by Isenegger et al. [7] for a thorough description.

curriculum aims to be **engaging**, as engagement may positively impact student interest in computing [9, 17]. It also seeks to encourage **creativity** [20] and enable students to explore and personalize projects at whatever their level of experience may be. Finally, the curriculum is designed to be sufficiently **challenging** such that students must grapple with new ways to solve problems with computational thinking but not overly challenging as to hinder their engagement [21]. The curriculum focuses on code reuse and modification to make these three principles as accessible as possible to a wide audience. In regards to teachers' experience, the curriculum aims to be easy to implement and flexible for multiple classroom contexts.

3.2 Curriculum Modifications

We modified the CS+X curriculum to fit our middle school population within an informal learning context. As the camps only lasted one week, and the curriculum we used was meant for an entire semester, we could only deliver a subset of the material to students. The modular nature of the curriculum (i.e., the standalone CS+X units) made the process of determining what to include fairly simple. We decided to have students work on a single Python project for the camp and to supplement this activity with videos, readings, and discussions from the other CS+X units. We chose the CS+Linguistics project because we believed it was an understudied portion of the CS+X curriculum and that it had several elements that could be engaging to a younger audience (e.g., part of the project is themed around a character "Frank the Cat", and another part of the project asks students to come up with silly words to generate new sentences). After devoting a large portion of the camp time to this single project, by the end of the week students developed some familiarity with Python coding and the field of CS+Linguistics, which has a number of important ethical issues for students to consider. At the same time, we were sure to include enough material from the other units (e.g., CS+Music, which extensively discusses artificial intelligence) to allow students a chance at exploration and to hopefully spark a variety of interests.

Reaching the younger students also necessitated implementing the curriculum with greater scaffolding on the Python project. For example, we dedicated time to making sure students could confidently describe that functions accept an input and return a subsequent output. These conceptual building blocks were an important base for students' to have to then feel successful engaging with the CS+Linguistics project.

Additionally, the informal learning environment's lack of certain external motivators, like grades, required changes to encourage engagement. While the CS+Linguistics project was originally written for students to be able to complete independently, our implementation had frequent check-ins and re-alignments from the instructor to keep students interested. Often, we would present students with a small program (i.e., a few lines of code) and ask them to explain what the code was doing. We used this practice to gauge an appropriate pace to move through the curriculum. Other active learning techniques we used include asking students to collaborate on short presentations answering guided questions and instructor-moderated group discussions about the material. Overall, we note that that improving students' attitudes, not their learning, was the primary focus of the camp. That being said, many students appear to have many learning gains at the camp (see Section 7).

Finally, we modified the curriculum to emphasize STEM degree and career pathways. While the original curriculum by Isenegger et al. [7] encourages students to connect their personal goals and interest with computing, there is not a focus on pathway exploration. Middle school students are likely still considering many potential pathways, and thus it may be important to directly expose them to a variety of possible futures. Each day, students learned about a career field utilizing computer science solutions. Instructors assigned students with a paper and video corresponding to the career topic as homework. Then, students worked in groups the next day to discuss what they learned and found interesting. Students' discussions were varied and demonstrated engagement with the material.

4 Study Context

4.1 Illinois Mathematics and Science Academy (IMSA)

The Illinois Mathematics and Science Academy (IMSA) is a public, tuition-free, residential high school (grades 10-12) established by the State of Illinois in 1985 to serve academically talented students from across the state and to advance access and equity in STEM education statewide through leadership, outreach, and professional learning. Approximately 70% of IMSA alumni earn bachelor's degrees in science, technology, engineering, or mathematics, reflecting IMSA's contribution to the development of a strong and diverse STEM workforce for Illinois. The IMSA Fund for Advancement of Education, a 501(c)(3) nonprofit governed by a Board of Directors, supports IMSA through private-sector fundraising and strategic partnerships. Philanthropic investments made through the IMSA Fund provide the margin of excellence—enabling innovation, expanding access, and strengthening experiential STEM opportunities that prepare students to become future leaders in Illinois's STEM workforce.

4.2 CS+X Summer Camps

IMSA offered two new camps in the summer of 2026: a CS+X girls summer camp, and a CS+X all-genders summer camp. IMSA regularly offers summer programs across mathematics, science, engineering, and computer science. The CS+X summer camps represented a new addition to this portfolio, testing the applicability of interdisciplinary computer science curricula for younger learners within a residential, informal learning environment. Each camp served 20 rising 8th and 9th grade students. Figure 6.2 shows the previous computing experience of the 38 participants who we have data on. Most of the students (45%) had some elementary coding experience (e.g., block-based coding), while 31% had no CS experience. A select group of 9 students (24%) had CS experience beyond the elementary level, such as experience with web-programming or object-oriented programming.

The CS+X girls summer camp aligned directly with IMSA's mission to broaden participation in STEM by offering a residential, interdisciplinary computer science experience for middle school girls. Designed as a pilot program, the camp sought to reduce early barriers to computer science, foster confidence and a sense of belonging, and introduce students to real-world, cross-disciplinary pathways that connect computing to a wide range of interests and careers. While the program was open to all students, all participants in this camp identified as girls. The camp did not collect data on students' race or ethnicity.

4.2.1 Recruitment and Advertising

Participants were recruited through IMSA's statewide outreach networks, including school districts, community organizations, and families, with targeted outreach to populations underrepresented in STEM. The camps were advertised through paid Facebook ads as a residential, immersive CS+X experience, and demand exceeded the available capacity of 20 spots per camp. The CS+X girls summer camp was entirely grant-funded (see Section 4.3), and thus financial need was prioritized in selecting students for this camp. The spots at the all-genders CS+X camp were filled on a first-come, first-served basis.

4.3 Duration, Residential Structure, and Cost

The CS+X summer camps were each one-week residential program consisting of five consecutive days and 40 total hours of instruction and engagement. Students lived on IMSA's campus and received housing and meals for the duration of the program [3]. The residential model was intentionally selected to promote community building, sustained engagement, and informal peer learning, with faculty, mentors, and resident counselors housed on campus to support supervision and student well-being.

Participants in the CS+X girls summer camp only paid a small administrative fee to attend. The total program cost for this camp was $25,000, supported by a Technology & Engineering Education grant from the Motorola Solutions Foundation with additional in-kind support from IMSA. Students in the all-genders camp were charged $500 for commuter enrollment, $1,200 for residential Illinois students, or $1,800 for residential out-of-state students.

5 Methods

5.1 Quantitative Survey Instruments

Students completed pre- and post-surveys designed to measure changes in *attitudes toward computer science*. Both surveys included the same set of questions assessing five validated constructs adapted from Haynie and Packman [4]. Each of these constructs is an important element for broadening participation in computing. We measured students' **confidence** in their ability to learn CS skills and solve CS problems, students' **interest** in learning computer science and solving problems, students' perceptions of **belonging** in computer science, students' beliefs in the **usefulness** of learning computer science, and students' perceptions of being **encouraged** to study computer science. Each construct consisted of five Likert-scale items, with responses ranging from 1 (strongly disagree) to 4 (strongly agree). We refer to these five constructs throughout the paper as the *attitudes toward CS variables*.

[3] Students in the all-genders camp had the option of commuting for a decreased program fee.

In addition to the attitude measures, the post-survey included a set of items aimed at capturing students' ***perceptions of the project*** which would help us evaluate our project design. These consisted of five Likert-scale questions: (1) *Did you find this project engaging?*, (2) *How challenging did you find this project?*, (3) *Did this project let you be creative?*, (4) *If you had more time, would you want to continue working on this project?*, and (5) *Were you surprised to learn that computers can write poetry?* For brevity, we refer to these items collectively as the *perception variables*, labeled as **Engagement**, **Challenge**, **Creativity**, **Persistence**, and **Novelty**. Each item was measured on a 1 (strongly disagree) to 5 (strongly agree).

5.2 Data Analysis

To answer our question, "Did students' attitudes towards computing become more positive?", we compared the pre- and post-survey results. We used two-sample T-tests to conduct this analysis with a significance threshold of 0.05. Results are described in Section 6.1 and Figure 6.2.

We conducted an additional analysis to answer the question, "What were students' perspectives of the CS+X curriculum?". We visualized the relevant post-survey results in Figure 3 and summarize our findings in Section 6.2.

6 Results

6.1 Changes in Students' Attitudes

We compared students pre- and post-survey results for our attitudes towards computer science measures and visualized the results in Figure 6.2. Recall that students answered these questions on a 4-point Likert scale. We found that some, but not all, measures had a statistically significant increase. Specifically, students' confidence increased from 2.77 to 3.04 (p-value: 0.04), their belonging increased from 3.03 to 3.27 (p-value: 0.02), and their encouragement increased from 2.97 to 3.30 (p-value: 0.00). Since this curriculum could be paired with other interventions to further increase students' positivity towards computing, the small increases we observed are also practically significant. While we saw a slight improvement in students' interest (3.17 to 3.28) and their beliefs about the usefulness of computing (3.19 to 3.21), these changes were not statistically significant (p values: 0.33 and 0.87, respectively).

6.2 Students' Perspectives of the Curriculum

To explore students' perspectives of the CS+X curriculum, we visualize the results of the relevant post-survey questions in Figure 3. The questions are centered on the CS+Linguistics project as students spent the majority of their time working on that assignment. The students rated the creativity element of the project most highly, with a mean score of 4.37 (SD= 0.82). At a close second highest was the project's ability to engage, with a mean score of 4.29 (SD= 0.98). The last question that students on average answered above the

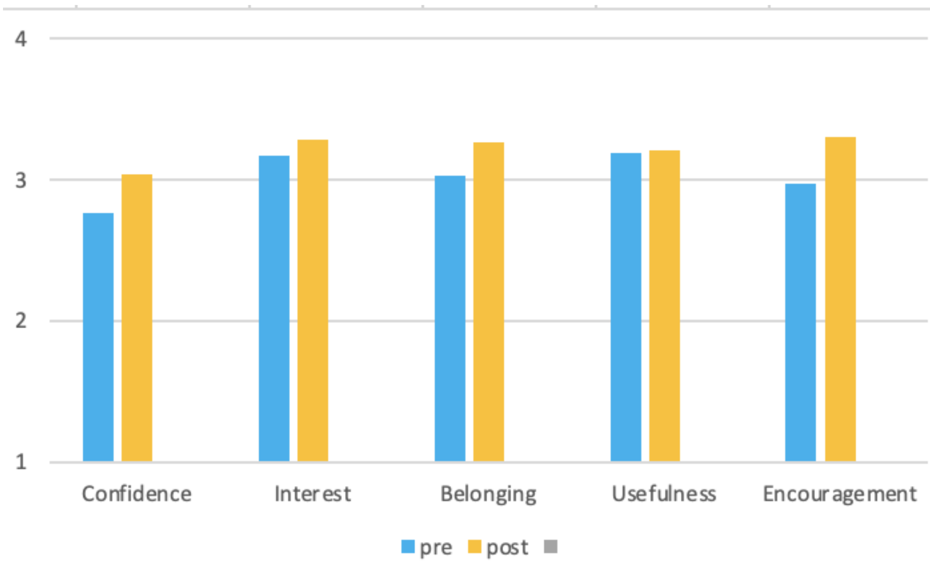

Figure 1: Computing Attitudes in Pre and Post surveys

middle of the Likert scale asked if they would like to continue working on the project. This question had a mean score of 3.76 (SD= 1.10). The last two survey questions evaluating the CS+X curriculum had mean scores just below the scale's mid-point. On average, students scored the project's element of challenge at 2.87 (SD= 0.85). The last question, meant to measure the novelty of the project topic to students, asked about their surprise to learn that computers can write poetry. For this question, we saw an average score of 2.82 (SD= 1.51). It seems that students were divided on this question with 17 answering one or two and 16 answering four or five.

7 Instructor observations and reflections

In this section, the camp instructors (authors two and three) add qualitative insights from the experience. They reflect on successes and challenges they observed with their students.

Overall, the instructors shared that incorporating CS+X curriculum into the camp was straightforward. Students seemed to retain a sizable degree of the lectures and exercises delivered over the week based on their interactions with instructors and peers. Most students had never programmed before– for example, some had never heard of Python. With a programming environment like Google Colab, students acclimated modifying and re-using code. While they were first wary of writing code at first, students grew more confident in their skills. This growth correlated with the complexity of questions asked by them. Most early questions from students were syntax-specific: for example, students needed help with using correct spacing and indentation in their code lines. By the end of the week, students were asking questions focused on the intent and utility of functions: using built-in functions versus manually typing the operation of the function was an eye-opening experience for students about code re-usability.

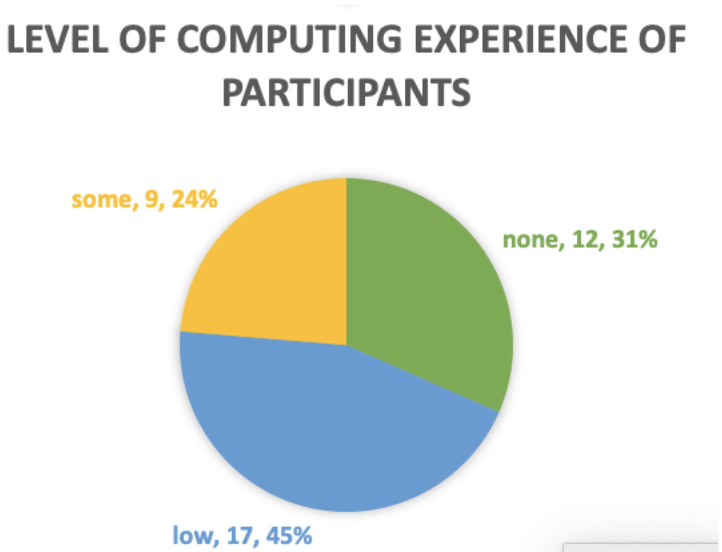

Figure 2: Computing level

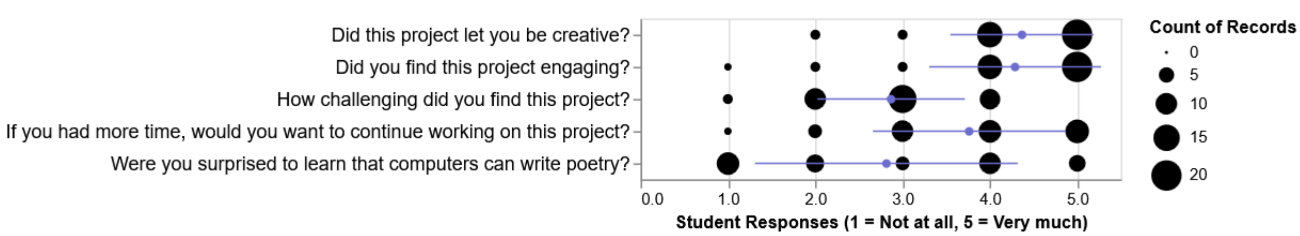

Figure 3: Computing Project Evaluation. Survey questions are shown on the Y-axis while student responses are shown on the X-axis. Larger circles indicate higher counts for that response. The mean and standard deviation for each survey question are shown in purple

7.1 Opportunities for Active Learning

The instructors also noted that the opportunities to incorporate active learning are a major strength of the CS+X curriculum in an informal learning environment for middle school students. Next, we discuss how the instructors were able to easily deliver the curriculum using active learning practices of peer learning and inductive teaching.

7.1.1 Peer Learning

Presentation assignment really encouraged students to go beyond the material presented in class and teach new things to their classmates. Students enjoyed working on their presentations and sharing them with their classmates. This class segment was more informal than the programming lectures, which would require students to be attentive. In contrast, working on presentations meant students could discuss with their peers what they had read and watched. This encouraged both discussion, brainstorming, and even debates within groups. The instructors emphasized collaboration and discussion in the classroom. Collaboration in the classroom meant students would work together in groups, either to answer questions on a program, write code, or create a presentation.

7.1.2 Inductive Teaching

Each lecture encouraged student participation by posing questions to the class, such as anticipating how the Python compiler would read a program. Then, students were challenged to solve a programming exercise with a partner. Students were encouraged to ask questions when they got stuck as they worked to form an understanding of the CS concepts.

7.2 Motivating Students

The instructors were able to motivate students with the inclusion of choices in the curriculum. At the start of the camp, they shared with students a brief overview of the different interdisciplinary topics included in the curriculum. They purposely included examples in this introduction that we hoped would make students curious about the topics. Then, they gave students autonomy by having them vote for what area to begin learning about. Based on our observations as instructors, we believe this was a successful way to motivate students.

Still, motivating particular students presented some challenges. A technique the instructors utilized to keep students engaged was diverse content delivery. They varied instruction between lectures, discussions, formative assessment worksheets, short coding exercises, and the multi-day Python programming project. The instructors observed that some students were inattentive during lectures and group work and subsequently struggled to complete formative assessments. This suggests that different motivational techniques may be needed to engage such students.

8 Conclusion

In this study, we sought to learn if IEE curricula could positively impact middle school students' attitudes towards engineering within an informal learning context. We made modifications to an existing IEE curriculum originally designed for a semester-long high school level CS+X elective course. Then, we implemented the curriculum with two groups of 20 middle school students during a week-long summer camp. Our findings show an increase in confidence, sense of belonging, and encouragement among students in the camps. Overall, students reported that the curriculum allowed for creativity, was engaging, and that they would like to spend more time learning with it. The camp instructors emphasized the ease of incorporating active learning practices and observed that most students were motivated by the curriculum.

We focused on an IEE curriculum for computing fields as this is our area of expertise. We believe studies that analyze specific engineering fields may help reveal nuanced details about IEE and how it differs between engineering disciplines. We encourage other researchers to investigate IEE curriculum for other engineering disciplines.

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