Engaging Secondary Students in Computing and Cybersecurity

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ABSTRACT

Institutions of higher education (IHE) have missions that include outreach to the potential pipeline to college, i.e., working with K12 students and teachers. In that vein, High Performance Research Computing at Texas A&M University has offered summer camp opportunities for secondary students since 2017. Each year staff members work to find better ways to engage students deeply in the activities and learning opportunities. For this paper, we chose to analyze the students' daily reflections to investigate evidence of student engagement and what promoted this engagement. Through thematic analysis, four main themes emerged: real-life applications, curiosity, collaboration, and problem solving. By providing experiences that immerse students in activities that are relevant to their everyday lives, create intellectual curiosity, facilitate collaboration, and present problems to be solved, students became deeply engaged in the learning. In a post-camp online activity three months later, students gave amazing examples of what they were doing to apply their learning and delve deeper into cybersecurity learning.

CCS CONCEPTS

• **Applied computing** → Education.

KEYWORDS

K-12 Outreach, Summer Camp, Computing, Cybersecurity

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1 INTRODUCTION

We live in a high-technology world with changes occurring daily, often hourly. Cybersecurity issues permeate our lives on a day-to-day basis, from the technology in our hands to our computers, to our Wifi connections, and to our cellular connections. All of these are vulnerable to attacks to gather our personal information, steal our identities, and take our money and assets. The purpose of this paper is to describe how research-based teaching strategies can be used to engage secondary students in rigorous learning of cybersecurity and computing in a summer camp experience. As background, we present literature about the types of teaching and learning activities that engage students in learning. We then describe how we applied these principles in our summer camps and give evidence of what engaged students in the learning, based on their daily reflections on their learning and enjoyment. Our research question was, "What facilitated engagement in the cybersecurity and programming activities in the summer camp among the student participants?"

Student engagement has been a struggle for classroom teachers for many years. In the learning environment, student engagement has been defined as "the place where students' emotional and reflective thoughts come together in their learning through participation in activities that foster both student motivation and active learning" (p. 289). [1] A variety of ideas have been presented as means to engage students in their studies. Punitive means have been minimally successful. A number of other ideas have been more successful, and research has backed up those claims, showing that engagement is strongly correlated with learning [2–4]. Thus, is it worthwhile to consider ways to engage students in informal as well as formal learning. Active learning has been credited with student engagement and learning for centuries. [5–7]. Collaborative learning is one effective active learning strategy to engage students, particularly if the task or problem to solve is organized in a way that students have feedback as they work together [8]. Escape rooms are a good example of collaborative learning and problem solving to engage students [1, 9]. Using real-life situations also engages students because they immediately see the relevance to their lives [10]. Most real-life situations have multiple solution methods, and often they have more than one solution. Perhaps the strongest link to student engagement is a curiosity about something. A strong curiosity propels the student to learn about that subject [11, 12]. Something that touches an individual's everyday life may create this curiosity to learn more about it. This may be the most important support for learning. Unfortunately, not everything that a

Figure 1: Example showing a secure system project

student needs to learn for the future has an immediate, accessible real-life problem that can be solved by the student. However, there are other ways to initiate or increase curiosity about a topic. One way is through puzzles. Students love to solve puzzles that fall within the range of proximal learning. In other words, it should be challenging, but not next to impossible for the student to solve at their level of knowledge and educational development [13].

2 METHODOLOGY

In June 2023, High Performance Research Computing conducted three one-week cybersecurity day camps for secondary school students. Python programming was used for some specific applications to cybersecurity, such as cryptography. Google Classroom was used as the means to organize the content, access Google Colab for Python, assign class work, and send the daily reflection survey. On the first day, after introductions of the teaching staff, counselors, and students, the students collaborated on an escape room activity. Rather than teaching the cybersecurity concepts by lecture, this activity required students to figure out how to match the definitions with the concept. After a fun mathematical puzzle, then the students matched each of the six concepts with a scenario that represented each one. Finally, they had to solve a puzzle to obtain the code to open a lock box. Inside was a certificate to "earn" their camp t-shirts. After the initial activity, students were led through hands-on activities that illustrated for the students one or more of the six principles of cybersecurity throughout the week. These included topics such as personal genomics and data privacy, social engineering, features of secure systems, flying drones through unsecured Wifi, a simulated cybersecurity attack, and cryptography. Python programming was used to extend the cryptography experiences and learn about machine learning and artificial intelligence. Students also toured the facility in which the high performance computers are housed and learned about the security needed for such systems. Each day the students worked in teams to design a fantasy secure system of their choice. They were required to show how one or more of the cybersecurity concepts they learned were integrated into their systems. Parents were invited to join the campers on the final day to watch them present their projects and answer questions from their fellow campers about the security of their systems. Figure 1 shows one of the presentation slides from the secure system design project. This group incorporated four of the six cybersecurity concepts in their design for a secure home. They described how each of these concepts were pertinent to their design. Many of the projects were well developed, illustrating the cybersecurity principles campers learned during the week. They enjoyed using their creativity in designing their systems and explaining their designs to their classmates and parents at the end of the camp.

2.1 Participants

Participants were 100 secondary school students who attended at least one day of one of the three week-long sessions of the cybersecurity summer camp in June of 2023 and completed the reflection at the end of the day. The demographic breakdown is given in Table 1.

2.2 Data Collection and Analysis

Data were collected through a Google form reflection at the end of each day of camp, Monday through Friday. Monday through Thursday, students were asked multiple choice questions about using the 21st century skills of collaboration, critical thinking, communication, and creativity in the day's activities. There were three free response questions:

- Which activity was your favorite? Explain why.
- From which activity did you learn the most? Explain why.
- Please share anything else you would like us to know.

The results from these three questions were gathered for qualitative analysis. The data from the daily reflections for Monday through Thursday for all three camp sessions were combined in

Table 1: Camper Demographics

Gender	Percentage	Ethnicity	Percentage
Male	63%	Asian	41%
Female	25%	Black or African American	8%
Did not specify	12%	White	42%
		Did not specify	9%

order to conduct thematic analysis [14]. Thematic analysis was used to learn how students became engaged in full participation in the camp activities related to cybersecurity concepts and Python programming. In this model researchers first break the data down into small bits and coded with key words that represent the idea presented [14]. Our data were naturally broken down because most of the student responses were brief, presenting only one idea or thought to be coded. Some responses contained two ideas, and both were included in the coding. A brief response example is, "Escape room due to team work." An example with two ideas is, "My favorite activity was the escape room, because it forced me to use my brain, and I enjoyed collaborating with my group." This response included the idea of solving a problem and collaboration. After the three researchers had coded their data and grouped them into themes, they met and discussed how and why they chose their themes. They discussed examples of responses for each theme and compared their themes. The theme development is more than noticing recurring ideas in the responses; it includes understanding and interpretation of the data. Thus, researchers discussed their individual work and how the concepts related to existing theories in research [14]. They discussed the relationship of the themes and concepts to each other to create a model to explain the results.

3 RESULTS

After the three researchers coded the student responses and found their themes, they discussed their findings. They were in agreement that there were four main themes present in the student responses that pointed to engagement in some way. To answer the research question, the four themes we found reflect what engaged students in the learning: real-life applications, curiosity, collaboration, and problem-solving. These were not mutually exclusive as it was impossible to completely separate these ideas in terms of student engagement. The researchers also found that different students expressed different reasons for being engaged in any given activity, showing that a given activity does not necessarily engage all students in the same way.

The most prevalent theme of engagement was **real-life situations**. With cybersecurity as the theme, every learning activity was based on applications students encounter every day. Almost every camper had a cell phone with them, and they worked on computers for many of the activities. Thus, they realized the vulnerabilities related to the choices they made with their handheld devices, computers, and smart appliances in their homes. Speakers gave anecdotal examples of authentic cybersecurity experiences. Implications of the topic were very important and commonly aligned with responses mentioning previous experiences and anecdotes. When the campers realized the implications, either by story or by lecture, the campers understood the importance of what they were learning. In all but one of the responses that mentioned the ransomware lecture, camper were engaged because they learned of immediate, present risks in their lives. Many campers enjoyed the story of the enigma machine because it showed the effectiveness of encryption and therefore its important use in their own lives for their data.

Curiosity is defined as "In a neutral or good sense: The desire or inclination to know or learn about anything, esp. what is novel or strange; a feeling of interest leading one to inquire about anything" [15]. Responses relating to curiosity fell into either a category of previous interest in the subject, or a category of using the lesson beyond what was learned. Campers mentioned engagement about learning how things operated such as drone communication by Wi-Fi or supercomputer cooling systems. Learning coding, about "Hackers", and supercomputers engaged students because of a pre-existing curiosity. Campers also took what they learned and worked beyond the required material. In the classes that involved Python, campers were engaged because they could "mess around" with what they learned. In cryptography, campers were excited to bring home their own cyphers and create their own code.

Peer **collaboration** and working in teams were mentioned in over 50 student reflections. Collaboration is defined as "the action of working together to produce or create something" [16]. It is a formalized process where individuals with different expertise come together to solve a problem or create something new. Teamwork is done by a group "acting together so that each member does a part that contributes to the efficiency of the whole" [17]. The activities in which campers worked together met either or both definitions. At least 60 students rated the escape room as one of their favorite activities. Students used words such as "informational about my group"; "introduction to team mates"; "sharing ideas", "working together to solve puzzles"; "made friends"; "sharing with table to figure things out"; and "got to know each other". This activity was the first activity of the day, so campers appreciated this opportunity to get to know the classmates that they would be working with throughout the week. Some responses indicated they enjoyed a social aspect. Collaboration necessarily involves this social aspect. These activities described by the students include learning in a way that provides social, collaborative, and a new shared experience. At the end of the week of activities, when students relayed their favorite activities - the escape room was still in the top three favorite activities. The escape room, "Capture the Pi Hat", cyber disaster simulation, and final camp project required combined efforts of each team member. Occasionally a staff member intervened to help students learn to listen to each group member and respect their ideas. The students reported that using cryptography and encryption techniques provided them the opportunity to collaborate with their group to share learning. Students also participated as a unit in the drone flying activity. After practicing flying the drones, students experienced losing control of the drones. They did not realize instructors in the room were interrupting the Wifi signals. They soon figured out what was happening and began trying to take control of a drone from another group. Students reported at least 73 responses regarding the drone activity as a favorite activity. As part of the Raspberry Pi "Capture the Pi Hat" activity, students were required to share some of their passwords for the exercise. This sharing increased the trust students had in each other, increasing their collaboration and personal responsibility within their groups. Other groups worked together to figure out the password and change it so that the original group could no longer access their raspberry pi.

By nature, STEM fields emphasize student learning through using abstract knowledge and applying real-world situations to engage students in authentic problems [18]. Recent studies have suggested complex processes for engaging students in **problem-solving** are complicated and include multiple steps such as framing the problem, analyzing, formulation of hypotheses, developing solutions and taking action. Such learning requires students to use complex and higher-order thinking skills that may not come easy to all learners [19]. Activities began with the escape room, then introduction to Python programming, and grew to more challenging projects such as cryptography, decoding, and the final project, designing a secure system using cybersecurity principles. Students reported that they enjoyed solving puzzles and working together to identify new solutions. Over 58 students reported the escape room as a favorite activity, citing solving the puzzles as the component that made their experience great. Students reported "escape room forced me to use my brain"; "escape room involved thinking and collaboration"; and "escape room used creativity and thinking skills". These are examples of how students employed collaborative problem-solving and utilized higher-order thinking skills to solve multiple problems at various levels of complexity. Studies showed that students have widespread misconceptions about "coding" that inhibit their ability to successfully learn Python [20]. Overwhelmingly when asked from which activities they learned the most, campers responded with "Python" over 100 times in their open-ended feedback. Comments included:

- "I learned the most from doing encryption in Python – it put all my skills to use and challenged me"
- "Python coding because I learned how to get the basics of coding like dicts, string, zips and much more"
- "Python is when the light bulb clicked for me"
- "Python encryption I learned the most from. I hadn't done that before and had no clue how to approach encryption"
- "I had little instruction in python coding so it was fun to get more information"

Problem-solving assignments increased in complexity and were embedded in lectures about the history of cybersecurity, cryptography, and how coding enables self-protection in our increasingly cyberworld. Activities in cryptography were especially popular in responses where students were able to discuss in what areas they learned the most. Cryptography was mentioned over 50 times with cybersecurity concepts ranked as the third highest area where students felt they gained the most knowledge.

4 DISCUSSION

The results of the themes we found for student engagement in the 2023 summer camps align well with the research. This information is useful to us and others who are interested in providing similar informal learning opportunities for secondary students. Real-life learning experiences are all around us. The challenge for educators is to bring these concepts down to the level of students so that they can access the learning [8]. Cybersecurity affects our lives every day, and students were interested in it for that reason. Learning more about it through active learning as illustrated by the drone activity and "capture the Pi hat" gave students an opportunity to experience cybersecurity concepts. They applied that knowledge to collaborate to design a secure system of their choice. Collaborative learning needs to be structured so that students have feedback along the way [3]. We accomplished this by having a counselor to mentor each group, helping guide them through the process without taking the lead. Curiosity is individual to each student. Children usually have an innate curiosity about the world around them, but it is sometimes crushed by strict regimens of exploration and learning. Curiosity can be encouraged by teachers who exhibit an excitement about learning. Students in our camp did note that one particular instructor was engaging because of his animation and enthusiasm. However, they enjoyed experiences led by others because they were interested in or had a curiosity to learn about the topic.

5 CONCLUSIONS

The results of this study have implications for further work with secondary students in STEM areas, and possibly all areas of educational instruction, both informal and formal. In considering how we facilitate student learning, we should try to find some way to engage students so that they delve deeper into the topic at hand to deepen their understanding and maximize the learning potential [11]. This strategy will pay dividends in terms of broadening student knowledge and interest as well because it brings them to the brink of a related topic that they have not yet explored. As learning connects to prior learning, it builds the student's network of knowledge and provides a greater opportunity to find areas of deep interest that could help students decide on college courses of study and careers.

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