Expanding Participation through Student-Designed Escape Rooms

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***Abstract*—The full paper describes secondary students' experience in a summer STEM camp in which they puzzled through and then designed escape rooms. The theoretical framework used is experiential learning as explained by John Dewey (1938). In this methodology, students learn from being immersed in situations that at least mimic real life, if not fully real-life. Educators are challenged to find materials for students to learn within some experience. As successive experiences are integrated, the learning progresses. If the learning is within the capability of the student, curiosity to learn more may be aroused, and the learning continues. First, the students were told how escape rooms work and were put into teams for the escape room activities. The instructors set up escape rooms for the students to try their hand at escaping, and competing in teams to see which team had the shortest escape time. After the students all had the opportunity to try out an escape room, they worked in teams to create their own escape room. Another camp session involved basic cryptograph with ciphers, primarily shift ciphers. A requirement of their designs was to include a cipher somewhere in the design. Students were given lock boxes, numerical, alphabetic, and emoji locks of various kinds to use. They worked through a process of 1) deciding on a theme, 2) creating various challenges and clues, 3) sequencing the clues, 4) creating hints, 5) and setting up the escape room. Finally, the four teams each had the opportunity to escape the other teams' rooms. The paper will describe more fully the students' engagement and reaction to the escape rooms as well as the collaborative discussions and learning. Informal learning experiences are an important part of the pre-college learning that engages students and increases their interest in STEM. Escape rooms are a great way to immerse students in collaborative learning and boost their desire to learn more.**

Keywords—STEM interest, escape rooms, experiential learning

I. Introduction

It is commonly known that there continues to exist a need for STEM majors and professionals. Success in STEM learning is one of the strongest influences in a student's decision to pursue a STEM field [1]. According to social cognitive career theory, students need to choose STEM learning opportunities in order to find success, but often prior success is present [2]. Thus, students need to be engaged in STEM activities that build confidence in STEM content, increase creativity in problem-solving, and provide information about what STEM professionals do in their jobs. Informal learning experiences can play an impactful role in broadening participation in STEM fields by engaging students in authentic learning and increasing their success in STEM learning

II. Theoretical Framework

A. Experiential Learning

John Dewey's theory of situated, experiential learning is the primary basis for the theoretical framework of this study. Experiential learning occurs in informal as well as formal learning environments and develops knowledge through engagement, experience, and practice [3]. David Kolb's experiential learning theory details a four-stage cycle [4]. This cycle is illustrated in Figure 1 below.

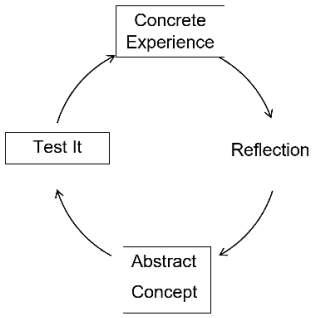

Fig 1. Kolb Experiential Learning Cycle

B. Engineering Design Process

The experiential learning cycle in Figure 1 also fits well with the engineering design process. There are several models for the engineering design process, but they are all cyclical processes that involve testing and revising the product created. Various engineering design processes are being used in K-12 education in order to improve engineering skills for creative and competitive engineers [5]. The design process for our theoretical framework is an iterative process that uses the experiential learning model in Figure 1, resulting in a process shown in Figure 2 below.

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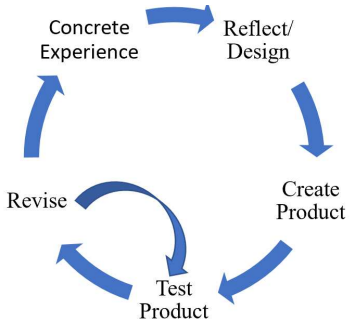

Figure 2. Engineering Design Process for Experiential Learning

C. *Escape Rooms in Education*

Escape rooms have become a popular activity in which a small group of people is locked in a room from which they escape by solving a series of puzzles in a limited time. Each room has a theme (e.g., super heroes, murder mystery, movie). Escape room businesses usually have several rooms with different themes and difficulty levels from which to choose. In recent years escape rooms have been used to help students learn material in a more enjoyable and memorable way. For example, escape rooms have been used in the medical field for problem solving while developing nursing, medicine, and pharmacy skills [6]. Escape rooms have also been employed for bonding of teams [7]. Only three manuscripts were found in which students rather than instructors created escape rooms. The students were college students, two involving undergraduates and one involving graduate students.

D. *Research Questions*

There is a gap in the research about having students below the college level create escape rooms. The only manuscripts we found that used escape rooms with these students were focused on using them as a fun way to learn certain materials. None of them used escape room design at that level. We wanted to try it out and see how well it worked to possibly address deeper learning in some way. The research questions for the study were 1) How did a one-week summer STEM camp affect secondary student STEM interest, and 2) What educational benefits could students gain by creating an escape room using an engineering design process?

III. Methodology

A. *Participants*

Participants were secondary students aged 14+ who attended a summer STEM camp at a university in the southwest in 2021. Table 1 shows the demographic breakdown of participants.

TABLE I. Participant Demographics

Race	Female	Male	Totals
Asian	3	4	7
Black or African American	4	5	9
Native Hawaiian/Other Pacific Islander	0	1	1
Whie, including Hispanic, Latino, and Spanish Ethnicities	10	19	29
Other	1	4	5
TOTALS	18	33	**51**

B. *Escape Room Design*

Experiential learning in an informal environment was provided to secondary students in summer 2021. The camp included several mini-courses, one of which was escape room design. The engineering design cycle for the escape rooms is shown in Figure 3 below. Note that there is only one iteration because the number of iterations in a design process is constrained by time.

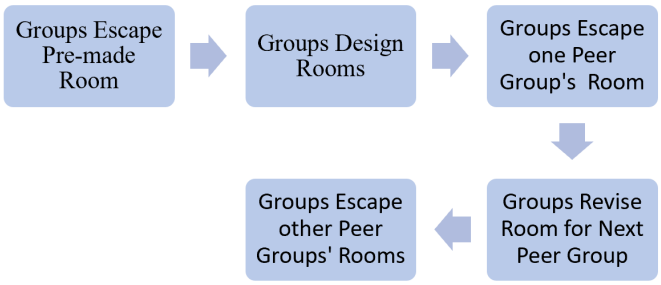

Figure 3. Escape Room Design Process

The pre-made escape room was set up from a purchased escape room package in order to save time in creating a complete escape room. We realized that students may not have had an experience with escape rooms; thus, they could not design such a game. The senior counselors set up the escape room. Students were divided into groups to work together throughout the escape room activities. In order to prevent the leakage of information to other groups, we told them it was a competition to see which group could escape in the shortest amount of time. We explained the rules of the game, and the senior counselors observed the students, providing clues when students got stuck and could not move forward, much like the commercial escape rooms.

The pre-made escape room was based on the theft of a painting. There were cards showing each of the paintings, and they were laid out on the table. There was a set of clue cards as well. The clues were used to eliminate all but one of the paintings, and the remaining painting was the one stolen. Participants then had to arrange a 3 x 3 grid of the numbers 1 through 9 so that each row, column, and diagonal totaled 15. The kit did not have locks or lock boxes, so we added a box and a cipher to solve in order to open the box.

On the second day of camp, we explained that the groups had to use at least one cipher for a clue in their designs, like the shift ciphers we had studied in the cryptography class. We showed them the variety of locks available for their use, as well as two different lock boxes. We put the groups in separate rooms to design their escape rooms. Originally, we only expected them to choose a theme and complete two or three clues and answers in sequence to escape the room. However, the students really got

into the project. They were creative with their stories about the situation from which they had to escape.

C. Data Collected and Data Analysis

Before camp activities began, students completed a pretest STEM interest survey. Several days during the five-day camp, students were asked to reflect on what they learned and what they enjoyed most. At the end of the camp activities, students completed a posttest STEM interest survey. Means, standard deviations, and the 95% confidence interval were calculated for the pretest and posttest survey of STEM interest.

In addition, counselors who worked with students in the escape room designing process reflected on the process and what they observed. One group of students also described their escape room design in some detail.

IV. Results

The means and standard deviations of the pretest and posttest for STEM interest are shown in Table 1, and the 95% confidence interval in Figure 4. The results were statistically significant ($p < .001$). Figure 4 gives a visual of the statistical significance, with almost no overlap in the confidence interval bars.

TABLE II. STEM Interest Survey

Pretest Mean (SD)	Posttest Mean (SD)
175.11 (22.54)	186.47 (19.35)

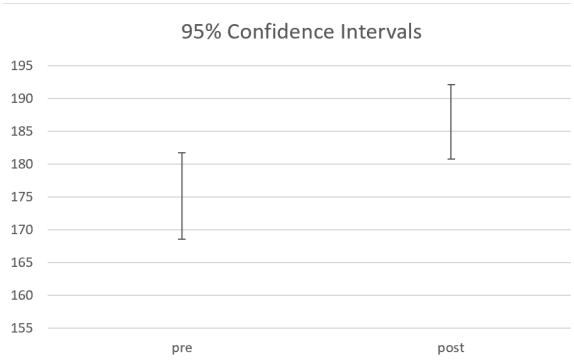

Figure 4. 95% Confidence Intervals for STEM Interest Survey

There was no way to know which STEM activities in the camp had the greatest effect on STEM interest. However, our first research question only addressed whether the camp had an effect. It could very well have been a combination of activities and learning more about the broad range of applications of STEM careers to which they had never been exposed. The other activities were 3D design, circuitry and coding with microcontrollers, and paper engineering (i.e., creating pop-ups). One or more activities had an effect on student STEM interest.

The second research addressed the educational benefits gained through the creation of escape rooms using an engineering design process. Although we introduced and engineering design process, we did not emphasize the term a lot. The process is very similar to Polya's problem solving process [9] with the addition of the emphasis on revision to improve the model

In the reflections from students about what they enjoyed most, the escape room design and cryptography were mentioned by about 30% of the responses. We coded student responses for educational learning themes because we wanted to know what learning students felt that they had gained. Three 21st century skills themes emerged in students' comments about the escape rooms [10]. First, they noted that they learned better problem solving. This speaks to the critical thinking skill that continues to be lacking in so many students. As we listened to them puzzling through the clues, we were pleased to see them asking each other, "Why do you think it is that? How do you know?" These are questions we want to hear in students' conversations in STEM classrooms. Secondly, students said they were able to use creativity in their work with the escape rooms. STEM careers, especially engineering, require creativity in order to solve problems in our world today. Thus, activities that advance problem solving in creative ways is of tremendous value. Thirdly, students wrote about working in teams to solve problems. They wrote about how they struggled in the beginning, but they learned to listen to everyone in the group, to value all ideas, and to work together. The descriptions that follow are examples that show more about what counselors observed and students described in their learning through escape room design.

One of the counselors who did not set up the pre-made escape room shared her experience with the group she observed designing their escape room and the groups who tried to escape that room. Here is her reflection.

> I had the privilege of being in the escape rooms when the students first did them, created their own, and did other students' escape rooms. Watching them create their own escape rooms was really interesting because they were pulling ideas from everything else we had done at camp during the week. The students really enjoyed using cryptography in their escape rooms. When they were solving each other's escape rooms, they had more fun than in the original one because their own creations were more challenging and personalized to their age group. This activity really encouraged their communication skills as well. Several kids would ask, "Why do you think this is the answer rather than something else?" I think the students really enjoyed getting to create their own escape rooms and applying the skills they learned earlier in the week.

Six months after the camp was over, we asked students if they would describe their memories of their escape rooms. The response rate was low, as might be expected, but some of them described quite a bit of detail. We let them know we were writing a paper about this topic and gained their permission as well as parental permission for those whose names we acknowledged. Although we had an IRB for the data, we wanted this extra layer of permission. Others were anonymous. One commented that her experience with the escape room was "definitely very memorable." The theme was that they were stranded on a ship at sea and had to find their way back to shore. They sketched a map, made a code, and hid some key items around the room. She noted also that she worked on getting her

group to work together as a team because "we all have bright ideas, and they don't necessarily coincide all the time."

A second escape room experience described by a student was that his group wanted to make the clues integrate with the them and make it "just difficult enough that they weren't impossible to find and rewarding." They put one of the clues in a cake, but "sadly, the cake was not real." He noted that he learned that creativity is a skill and that "putting together a project that satisfies all group members is fun."

A third group used the theme of Jack the Ripper with a murder to solve. One group member notes that the escape room helped them work with a group of people she had not know before, and how to give everyone a chance to speak and share ideas without disregarding other people's ideas and that it was great to apply the ciphers they had just learned. Another group member also mentioned that he learned "historical events as well as the practical application of ciphers." A third group member didn't remember as much of the thought process as the "bonding experience I had with the group." He noted that an unexpected turn in the process was that "our unsub was a woman!" He commented on the number to letters cipher was "cool" to learn how to do. He commented, "If I had the opportunity to do it again, I will do it in a heart beat, one of the best experiences I had. I learned many things at camp, but I remember the most the experience of the bonding with others, working with a team, and being creative!"

V. Conclusions and Implications

Designing escape rooms gave students an opportunity to use their creativity in a problem-solving situation that was fun and challenging. The experience also helped students work collaboratively to design the puzzles and to solve the other puzzles. This camp was some students' first opportunity since the pandemic began to actually work collaboratively. They were from a number of different school districts in the area, so they did not all know each other In a few hours a day for five days, they learned to work together and really enjoyed it. This is evident in their comments about what they learned and enjoyed. Many of them mentioned their learning in working together and in using their creativity. Designing escape rooms was beneficial to students in learning to use their creativity, to work collaboratively to design a room and to solve puzzles in other rooms, and to apply their knowledge of cryptography ciphers. In addition, they were able to experience a bit of an engineering design process when they corrected error or modified their rooms for more ease or difficulty after the first group tried to escape.

We plan to use escape room design again in future camps. We hope to gain more insight and be able to study more closely the student educational gains through escape rooms. We are always looking for different ways to engage students in activities to increase STEM content learning or to build 21st century skills that all students need. Often STEM camps are attended by students who already have an interest in STEM. We kept the content at a level we felt was accessible to all high school students and had enough counselors circulating to make sure they had any help they needed. We advertised the camps for ALL students who met the funder's requirements of being 14 years old by the first day of camp. They did not need to excel in any STEM subject. Thus, more parents possibly sent their children who were not particularly interested in STEM subject to attend the camp. A number of campers told us their parents made them come but by the end they were glad they did.

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