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Escape Rooms Inspire and Educate Undergraduate Students

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Statements and Declarations

Ethical Approval: This study was approved by the Otterbein University Institutional Review Board (IRB ID: HS #24/25-44). The methodology and assessments used in this study involved human participants and were conducted in accordance with the ethical standards of the 1964 Helsinki Declaration.

Consent to Participate: This study employed human subjects. All participants provided informed consent stating awareness of the ability to withdraw from study participation at any time and that all data would be reported without identifying information.

Consent to Publish: Written informed consent for publication was obtained from all participants of the study. Participants were over 18 years of age.

Competing Interests: The authors have no conflicts of interest that pertain to this article.

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Data and Materials Availability: All data generated or analyzed during this study are included in this published article and its supplementary information files.

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ABSTRACT

Escape rooms have become wildly popular amongst the general public. In addition, physical and digital escape rooms have increased in popularity for educators, especially within healthcare education sectors. However, there is a noticeable gap in research regarding the use of educational escape rooms in other areas of higher education. For this study, we designed a physical educational escape room for an undergraduate sophomore-level Cell Biology course as part of a required laboratory component. Students completed a pre-quiz and post-quiz, and before and after student attitude surveys. The escape room was evaluated on a variety of parameters that connect to the following four pillars which were uncovered in our research: Engagement, Collaboration, Interdisciplinary Connections, and Logic. Most students agreed that the escape room increased their interest in cell biology in post survey evaluations. Students also responded that working as a team was supportive to their learning experience. The majority of students claimed to have an improved understanding of interdisciplinary connections in solving real-world problems and believed the escape room increased their learning experience. Most notably the mean quiz scores significantly increased ($p = 0.0015$) from 10.3 to 10.9 when comparing pre-quiz and post-quiz scores. This study addresses the need for research regarding the use of educational escape rooms and how they may improve student learning. The escape room utilized active learning, more specifically Game Based Learning (GBL) and Team Based Learning (TBL) theories. The results of this study support growing evidence that both learning theories enhance learning experiences and increase learning outcomes.

INTRODUCTION

Escape Rooms have become very popular amongst the general public, providing a unique form of entertainment where small groups of individuals must work together to solve a series of puzzles that are typically part of a larger storyline confined to a room or series of rooms. The ultimate goal is usually to solve a mystery and “escape” the room. Because these physical escape rooms are so popular, more and more companies have built escape rooms in and around cities throughout the world with a wide variety of themes (Spira, 2024). Additionally, there has been an explosion of commercially available escape room card games and board games as well as some companies

developing digital escape rooms. Educators have recently become highly interested in the use of game-based learning (the use of games for active learning in the classroom setting) to inspire student interest and engagement in particular topics (Veldkamp et al., 2020). Physical and digital escape rooms already known for their popular entertainment value among varying age groups represent compelling ways to increase student interest in various topics while potentially introducing learning gains as well.

Within an educational context, digital escape rooms sometimes in the form of escape room slides have been created by educators and there are various templates available online. These online games provide an easily accessible way for students to interact with the subject matter in a fun and engaging way. Physical Escape Rooms for the classroom setting are also of interest to educators and have been termed Educational Escape Rooms. Both physical and digital escape rooms have been increasing in popularity among educators during recent years, especially within various fields of healthcare education. Training of nurses, physicians, and other healthcare workers represents some of the most prolific literature available for this relatively new form of educational game-based learning (He et al., 2024; Quek et al., 2024; Torre et al., 2024; Fernandes et al., 2025; Kakos et al., 2025; Köse and Özcan, 2025). Although there are many new studies becoming available surrounding escape rooms, especially in nursing education, these are scattered across both digital and to a lesser extent physical escape rooms. They also are largely driven by student attitude surveys with not much information about actual learning gains, as seen in the references above. As a whole, there are very few studies available for the use of educational escape rooms in STEM higher education outside of healthcare fields. Here we describe a study where the use of a physical educational escape room was used in an undergraduate sophomore-level Cell Biology course as part of the required laboratory component. This study incorporates a pre-quiz and post-quiz as well as before and after student attitude survey questions which indicate increased student interest as well as both perceived and actual learning gains.

MATERIALS & METHODS

Methods Overview

A physical educational escape room was designed for use in the sophomore-level cell biology laboratory course at a small undergraduate liberal arts university. The goal of the escape room activity was to provide students with an immersive, engaging, and interactive learning enhancement activity towards the beginning of the semester. It also provided valuable insight into using games and interactive, collaborative activities in higher education STEM classrooms. Students were able to collaboratively engage with course-relevant material to further develop their understanding of fundamental cell biology concepts. To achieve this, a variety of puzzles, including combination locks, hidden objects, physical puzzles, logic puzzles, ciphers, and task-based puzzles were used.

Student Demographics and Backgrounds

A total of 63 students participated in the escape room activity. All of the participants were students in a sophomore-level Cell Biology course at Otterbein University. The cell biology course is a part of the required curriculum for Biology and Biochemistry and Molecular Biology (BMB) majors. It is also a required prerequisite for a variety of graduate and professional programs including medical, veterinary, and dental schools.

Of the 63 students who participated, 36 students were Biology majors, 20 students were BMB majors, 19 students were Zoo and Conservation Science majors, 3 students were Environmental Science majors, and 1 student was a Chemistry major. 16 students selected “Other” (Online Resource 1). “Other” majors included nursing, pre-equine veterinary studies, and life science education. 20 students were double majors, 5 students were triple majors, and 1 student was a quadruple major.

Cell Biology is a sophomore-level course and the majority of students take this during their sophomore year, however for a variety of reasons students may take the course during a different year, such as advanced placement or college credit plus from high school, or the desire to add another major. Out of 62 responses from students participating in the escape room activity, 7 students were first-year students, 28 students were sophomores, 20 students were juniors, 6 students were seniors, and 1 student was in their fifth year (Online Resource 1).

Students were able to select their own group of seven to eight students with the only restriction being that the group members had to be a part of the same lab section. Three lab sections participated. The first laboratory section had 22 students. The second laboratory section had 16 students, and the final laboratory section had 24 students.

Story Boarding

A story consisting of a few characters and a simple plot was provided to the students upon entering the escape room enacted by the instructor or teaching assistant who was dressed in laboratory attire fitting with the storyline. Since this course is typically a required course for certain majors or as a prerequisite for professional and graduate schools, the background story focused on diagnosing and resolving a medical mystery. The students worked as a team assuming the roles of epidemiologists and laboratory technicians as they solved puzzles related to protein structure, function, and amino acids with the ultimate goal of finding out why the fictional patient was ill. The story provided context to the participants while also exemplifying how cell biology can be used in a real-world setting.

Puzzle Design

Puzzles were designed using combination locks, ciphers, visual blocks, and word riddles. The materials were purchased and collected from online sources, the university

copy center, and from recycled materials. The puzzles were designed to employ different modalities of learning such as visual and tactile. The content of the puzzles was carefully selected from a predetermined set of learning targets for the cell biology course. The puzzles aimed to utilize the learning targets to actively engage the students with the material.

Activity Staging and Participation

To set up the escape room activity, a laboratory classroom was reserved prior to the event to allow for more accurate theming. The space was also chosen in this case so the professor and the teaching assistant were able to sit in the hall and directly observe the activity through the glass wall of the laboratory. Another space was reserved to act as the holding space before participants entered the escape room. That is where all surveys and assessments were completed.

When the students had completed the pre-survey and the pre-assessment, walkie talkies were used to communicate between the TA and professor in the escape room. Students were escorted from the holding space to the escape room to begin the activity and given one of the walkie talkies to communicate with the professor and TA who were stationed immediately outside of the laboratory classroom. They were provided with a short introduction that included rules, procedures, and a brief back story before beginning the activity. A timer was set and projected onto the classroom screen counting down the time left from 50 minutes. When the students completed the activity, the time it took them to complete it was documented and they were escorted back to the holding space. Then, the post-survey and post-assessment were conducted.

The placement of the puzzles was determined with desired difficulty and overall safety in mind. When planning the location of the puzzles, special consideration was taken to ensure that any hazardous equipment or materials were not accessible. Clear instructions were also provided to ensure students knew which areas were off-limits during the activity. The puzzles were placed so the participants would have to actively participate in the activity to be able to locate them, but not so difficult that the activity could not be completed.

Guidelines and Rules

Students were given 50 minutes to “escape the room”. To successfully complete the escape room, students had to complete nine puzzles and correctly enter a code into a lock box to get “the antidote”. The goal was to complete all of the puzzles in the least amount of time. Students were allowed one hint that could be utilized at any point during the Escape Room by using the walkie talkie that they were provided at the beginning of the activity. They were not allowed to use any computers, phones, or internet to solve any of the puzzles.

For the safety of the students, no doors were locked, and the walkie talkie could also be used to communicate with the instructor or teaching assistant. Since this experience took place in a laboratory setting, any cabinets or drawers that were not utilized for the Escape Room were clearly marked and students were instructed that no

locks should be forced open. At the end of the experience, students radioed the professor and teaching assistant so the time taken to complete the Escape Room could be recorded.

Survey Data and Analysis

The pre-survey and post-survey were ungraded online surveys completed by students using Qualtrics software before and after the activity respectively (see Online Resources 2 and 3 for survey results; identifying demographic data has been removed). The goal of the surveys was to gather demographic information, such as year in college, majors, and minors, self-reflection information on how they view learning and collaboration, and insight into how the activity was perceived by the participants. Online Resource 1 contains graphs to some of the survey results not shown in the main text.

The results of the surveys were compiled into spreadsheets and statistical tests, the T-test and Spearman Correlation test were conducted to evaluate any significant correlations.

Assessment Data and Analysis

A scored multiple-choice assessment (Online Resource 4) was taken at the beginning and end of the activity to evaluate learning and growth. The content of the assessment was developed to be level appropriate in difficulty and to test concepts relevant to the cell biology coursework. The questions were unchanged on the pre-assessment taken immediately prior to entering the escape room and the post-assessment taken immediately following the escape room activity to allow for accurate evaluation of learning gains or losses. The results of the assessments were recorded in a spreadsheet and evaluated using a T-test.

RESULTS

Escape Room Participation and Completion

62 Cell Biology students, participating in 8 groups were able to escape in an average/mean time of 30 minutes and 0.25 seconds. The fastest group escaped in 21 minutes and 57 seconds and times ranged to 37 minutes and 23 seconds. One group asked for a hint and another group completed the escape room while inadvertently bypassing at least one puzzle. The 50-minute time allotted was sufficient for all groups to complete the escape room.

Students Enjoy the Educational Escape Room and Show Increased Interest in Cell Biology

Overall, the majority of students (91.9%) indicated in the post-escape room survey that they enjoyed the “Locked in the Lab” escape room experience (Fig 1A). The students (77.4%) also indicated that they would like to see the use of educational escape rooms

within other classes (Fig 1B). The majority of students stated that the escape room increased their interest in the cell biology topics being tested (Fig 2A and 2B). For example, a majority of students (62.9%) agreed that the escape room increased their overall interest in cell biology (Fig 2A). Furthermore, a strong majority of students (79.0%) indicated that the use of puzzles and problem-solving within the escape room increased their curiosity pertaining to cell biology topics such as proteins and amino acids (Fig 2B). Many students highlighted the escape room as a fun activity that illustrated interdisciplinary connections between fields. Students also noted enjoying the timed aspect which created challenge and competition along with collaborative effort in this hands-on learning experience. All these aspects were reported to increase their interest in cell biology which is included in Student Testimonials (Table 1).

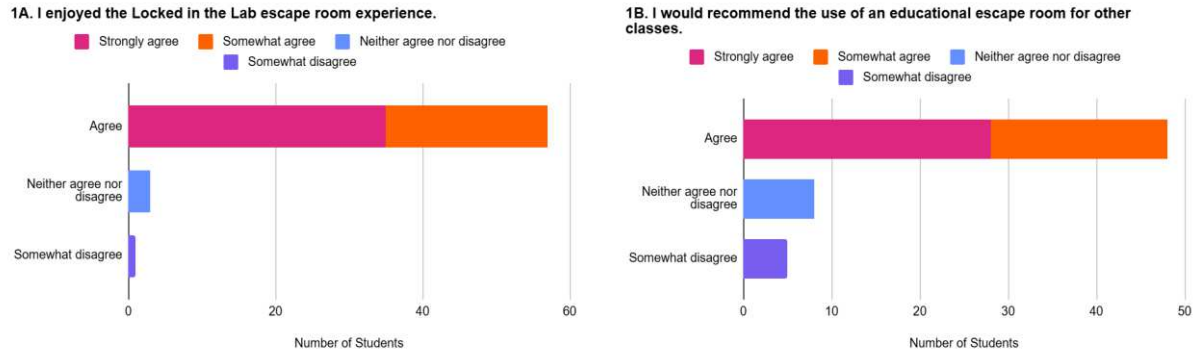


Fig. 1 Student enjoyment of Escape Room and recommendation for use in other classes

A. Students rated their enjoyment for the Locked in the Lab escape room post experience. 57 students (n = 62) agreed that they enjoyed the escape room experience with 35 students strongly agreeing and 22 students somewhat agreeing with the statement
B. Recommendation for the use of educational escape rooms in other classes. 48 students (n = 62) agreed that they would recommend an educational escape room for other classes. Of the 48 students, 28 students strongly agreed with the statement, and 20 students somewhat agreed with the statement. 5 students somewhat disagreed with the recommendation of utilizing an educational escape room for other classes

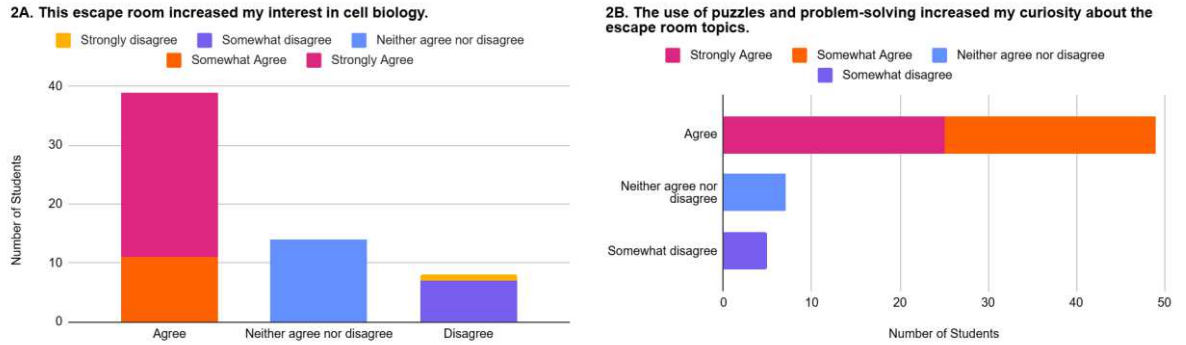


Fig. 2 Student Interest and Curiosity regarding science topics after Escape Room experience

A. Escape Room generated increased interest in cell biology. In student evaluations post-escape room, 39 students (n = 62) agreed with the statement that the escape room increased their interest in cell biology, with 28 students strongly agreeing and 11 students somewhat agreeing. Only 1 student (n = 62) strongly disagreed with the statement.

B. Using puzzles and problem-solving increased curiosity in escape room topics. In student evaluations post-escape room, 49 students (n = 62) agreed with the statement that the use of puzzles and problem-solving increased their curiosity about the escape room topics which largely focused on proteins and amino acids. 25 students strongly agreed with the statement while 24 students somewhat agreed. No students strongly disagreed

Table 1. Selected Student Testimonials for Increased Interest in Cell Biology. *(Post Survey Question 13. Explain why you felt this activity [Escape Room] was most effective at increasing your interest in cell biology.)*

"I like competition so having a timed challenge made learning fun"
"It was very interactive and I really enjoyed having fun while also doing cell biology"
"This allowed me to understand when this information would be used again and how it connects to other jobs. As someone who struggles to find interest in cell biology alone, this created interest to learn about it"
"It gave me the opportunity to learn in a different setting with the help from group members"
"I felt that this activity was the most effective at increasing my interest because it was a hands-on activity and it helped to work with others."
"It really ties everything together and you must have a good grasp on several subjects in order to move through the escape room swiftly."

Teamwork Enhanced Learning and Improved Sense of Belonging

Due to the escape room being completed in groups, we wanted to investigate how well students worked as a team and the effects of that teamwork on learning and sense of belonging. The majority of students (95.2%) indicated that they believed their team worked well together and communicated effectively (Fig 3A). A majority of students (82.2%) also indicated that working in a team within the escape room was beneficial and supportive to their learning experience (Fig 3B). In addition, students (72.6%) stated that their sense of belonging improved by being part of a team in the escape room (Fig 3C).

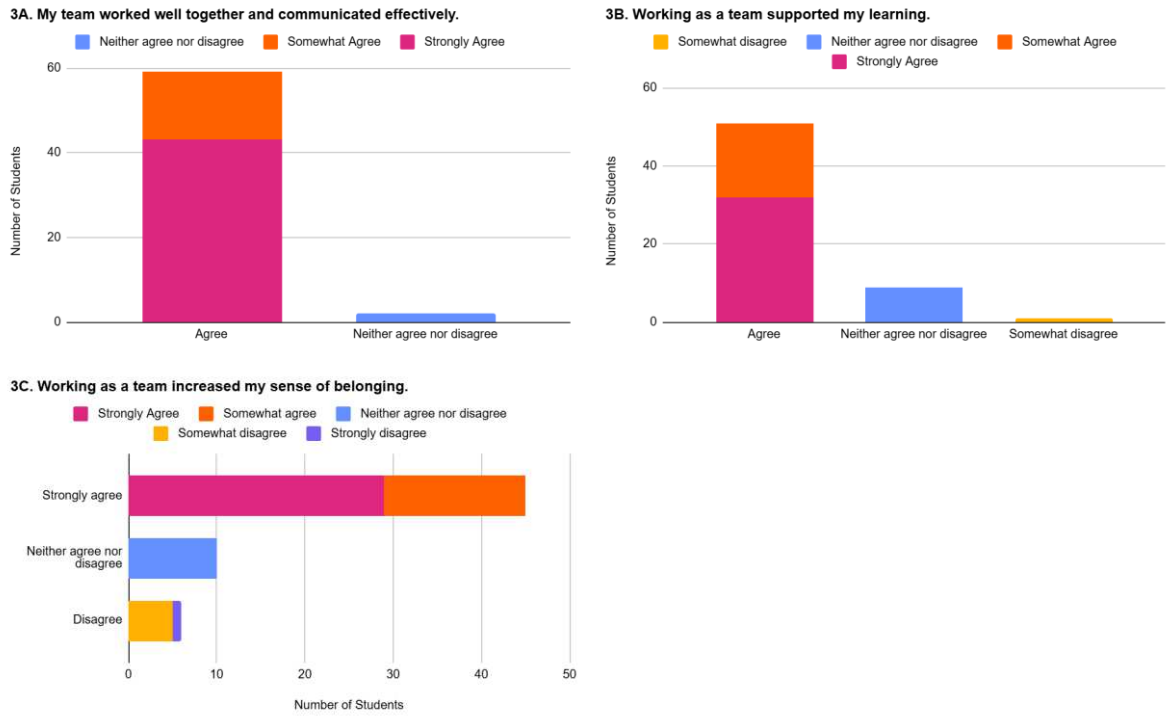


Fig 3 Student responses on how Teamwork impacted their learning and sense of belonging

A. Students rated how well their team worked and communicated effectively. 43 of 62 students strongly agreed that their team worked well together and communicated effectively. 16 students somewhat agreed with the statement while 2 students remained neutral regarding the statement. No students disagreed with the prompt
B. Students stated that working as a team supported their learning. 32 students strongly agreed and 19 students somewhat agreed (n = 62) that working as a team supported their learning in the escape room. Only 1 student somewhat disagreed with the statement. No students strongly disagreed
C. Increased sense of belonging from working as a team in the escape room. 45 students (n = 62) report agreeing that teamwork within the escape room

increased their sense of belonging with 29 students strongly agreeing and 16 students somewhat agreeing. 6 students disagreed that working as a team increased their sense of belonging with 1 student strongly disagreeing

Escape Rooms May Amplify Perceptions of Leadership

Prior to the escape room, almost half of the students indicated that they somewhat agreed (46.8%) and many strongly agreed (16.1%) with considering themselves to be a leader (Fig 4A). A total of 62.9% of students in the course considered themselves to be a leader prior to beginning the escape room. The post-experience survey revealed that the same percentage of students agreed that they felt like a leader while within the escape room solving one or more puzzles, but there was an evident shift with more students strongly agreeing (29.0%) as compared to somewhat agreeing (33.9%) that they felt like a leader within the escape room while solving one or more puzzles (Fig 4B). In addition, there is a strong correlation between students who indicated that they considered themselves to be a leader and those who felt like a leader through one of the puzzles in the escape room (r = 0.507).

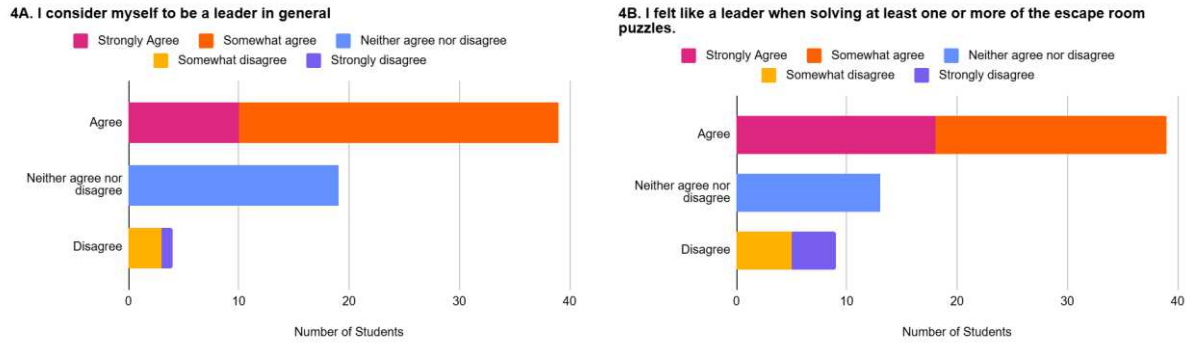


Figure 4 Pre and Post Escape Room Perceptions of Leadership
A. Preliminary student thoughts on defining themselves as leaders. 10 students (n = 62) strongly agreed that they identify as leaders in general prior to the escape room. 29 students somewhat agreed with considering themselves to be a leader before the escape room. 3 students somewhat disagreed with identifying as a leader
B. Student thoughts on feeling like a leader within the escape room. 18 students strongly agreed that they felt like a leader while solving one or more of the escape room puzzles. 21 students indicated that they somewhat agreed with feeling like a leader while solving escape room puzzles. 5 students indicated they somewhat disagreed with feeling like a leader while solving escape room puzzles while 4 strongly disagreed

Perceived and Actual Learning Gains

The post-survey described above included questions about perceived learning gains. To assess actual learning gains, students were given the same short 15-point multiple-

choice quiz immediately before entering the escape room and immediately following the experience. After the escape room activity, 60.7% of students stated on the survey that they thought the escape room enhanced their learning experience (Fig 5A). The majority of students (56.5%) agreed that puzzles and problem-solving within the escape room increased their learning of cell biology topics tested (Fig 5B). Prior to the escape room, students scored an average of 69.07% correct on the quiz. After the escape room, students scored an average of 72.67% correct on the quiz. Student responses to why the escape room enhanced their learning could be assigned to four different categories that we refer to as pillars in the discussion: Fun and engaging, Logical, Teamwork, and Interdisciplinary Connections (Table 2).

When comparing quiz scores (maximum of 15 points) before and after completing the escape room, the mean significantly ($p = 0.0015$) increased from 10.3 to 10.9 points. There is also an observed shift in the ranges after completing the escape room with the post-experience assessment scores being 6 to 15 compared to 4 to 15 points prior to the escape room (Figure 6A). There is a noticeable shift to the right between quiz scores when comparing pre- and post-escape room, indicating that quiz scores tended to increase after the escape room (Fig 6B). In addition, 31 students were able to increase their post-quiz score after completing the escape room, although 11 student scores dropped after the escape room (Fig 6C).

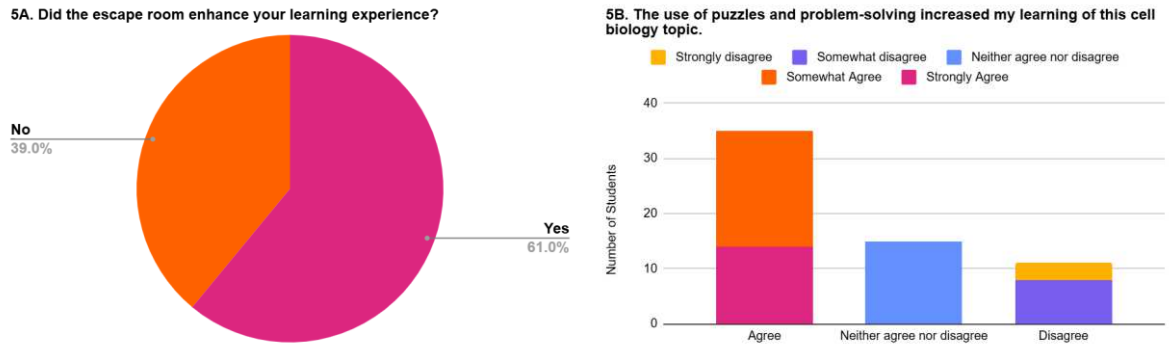


Fig 5 Perceived Learning Enhancement and how puzzles affected their learning after the Escape Room

A. Perceived Learning Enhancement of Escape Room. 60.7% of students indicated that they believed the escape room enhanced their learning experience
B. Students reported increased learning of cell biology due to using puzzles and problem-solving within the Escape Room. 35 students (n = 62) agreed that the use of puzzles and problem-solving increased their learning of the cell biology topics incorporated into the escape room, while 11 students disagreed with the statement

Table 2. Selected Student Testimonials for Increased Learning in Cell Biology
(Post Survey Question 8. If the escape room enhanced your learning, describe how.)

Characteristics	*Student Testimonials*
Fun and Engaging	• *"It made it a lot more interesting because it felt like we were playing a game. I really like playing games and winning-- In this case beating the timer-- so my engagement and ability to learn was high."* • *"Made learning enjoyable"* • *"I felt more engaged and focused."*
Logical	• *"It made me think more outside the box and logically. Also assisted in adapting to time pressure."* • *"It made me recall the amino acid abbreviations."* • *"Tied biology concepts into hints needed to solve the escape room."*
Teamwork	• *"It was a fun way to apply what we were learning in class that also allowed for collaboration."* • *"I thought it was a good way to show teamwork and other people's ideas or facts about the things we were looking for."* • *"I enjoyed working with different people to solve one common goal"*
Interdisciplinary Connections	• *"Relating all the topics to each other helped me to build new understandings about their connections."* • *"It allowed me to piece things together."* • *"It made me think and connect cell bio topics to the escape room."* • *"It made learning more enjoyable and helped pull the concepts together for me."*

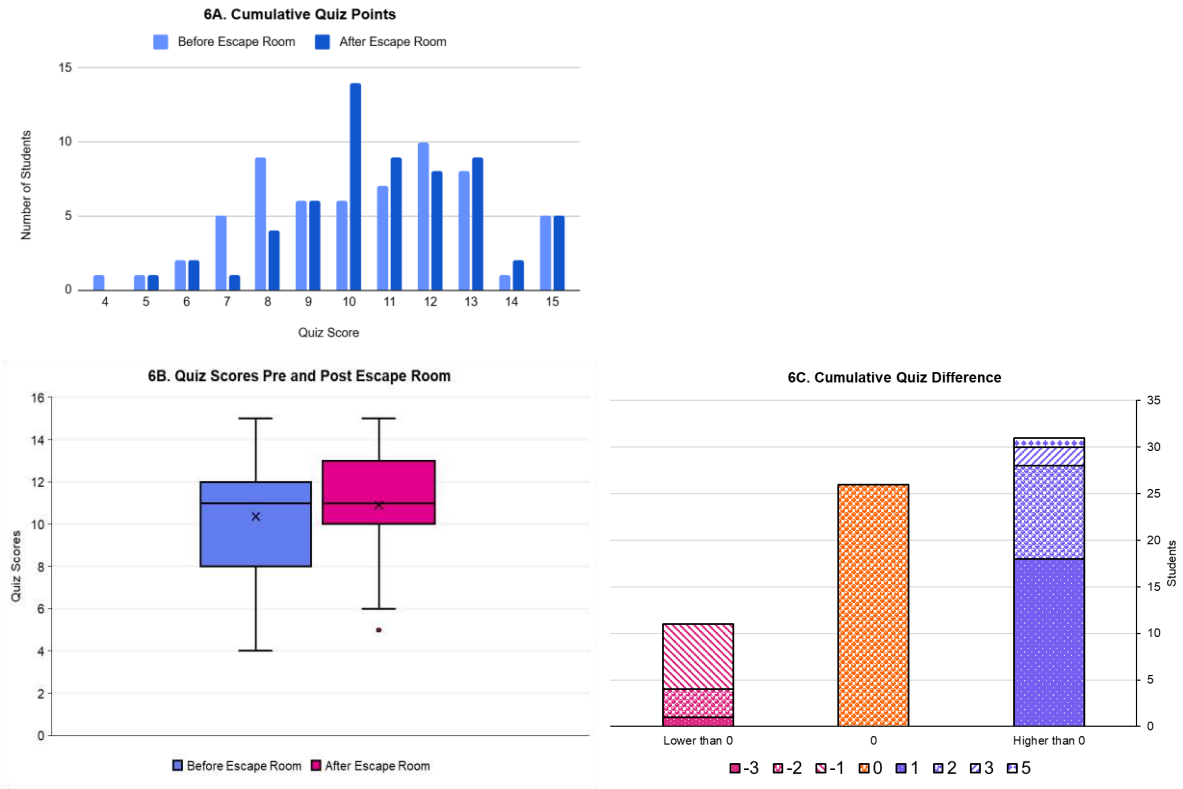


Fig. 6 Quiz Scores and Difference Before and After Escape Room.

A. Cumulative Quiz Points for Pre and Post Escape Room. There is an evident shift in the scores after the escape room to the right. For example, 24 students scored below 10 points immediately prior to the escape room, while only 14 students scored below 10 points immediately following the escape room.

B. Box and whisker plots of Quiz Scores before and after completing escape room. Before entering the escape room, the mean quiz score was 10.3 and the median was 11. The range of scores before the escape room was 4-15 with the lower interquartile range at 8 and the upper interquartile range at 12. After finishing the escape room, the mean quiz score was 10.9 and the median was 11. The range of scores after the escape room was 6-15 with the lower interquartile range at 10 and the upper interquartile range at 13. Means are marked by X on the box and whisker plots

C. Cumulative Quiz Difference. 31 students achieved a better score on the post-quiz with a cumulative quiz score difference of +1 or greater. 26 students had no change between pre and post quiz scores. 11 students showed a negative cumulative score difference when comparing pre and post quiz scores

Enhanced Learning Outcomes from Escape Room

The escape room was run four weeks into the semester, giving students some time to experience other aspects of the course. When asked which class activity was most effective in increasing their interest in cell biology, most students (38%) chose the Escape Room as compared to the more traditional teaching methods of lecture, lab, and

concept mapping that were also used in the course (Fig 7). Lecture was selected by 31% of the students with traditional lab experiments and concept mapping chosen by 16% and 15% of the students, respectively. A punctuated lecture approach is used in this course with short video clips and various active learning strategies incorporated into most lectures.

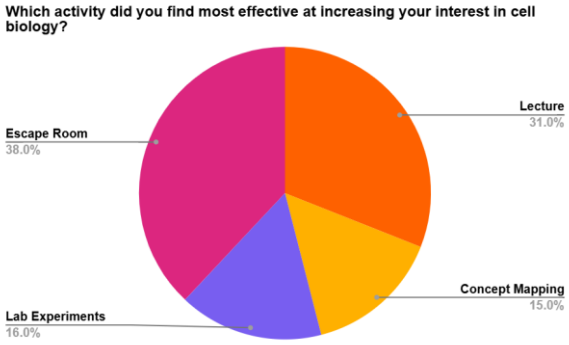


Fig. 7 The Most Effective Activity at Increasing Interest in Cell Biology. The majority of students indicated that the escape room was most effective for increasing their interest in cell biology (38%) when compared to lecture, lab experiments, and concept mapping.

Applications of the Escape Room in the Real-world

A large majority of the class of 62 students indicated that they believed the Escape Room emulated a problem-solving scenario that health professionals may use at 75% (Fig 8A). In addition, students (80.0%) stated they had an improved understanding for interdisciplinary connections in solving real-world problems after completing the Escape Room (Fig 8B).

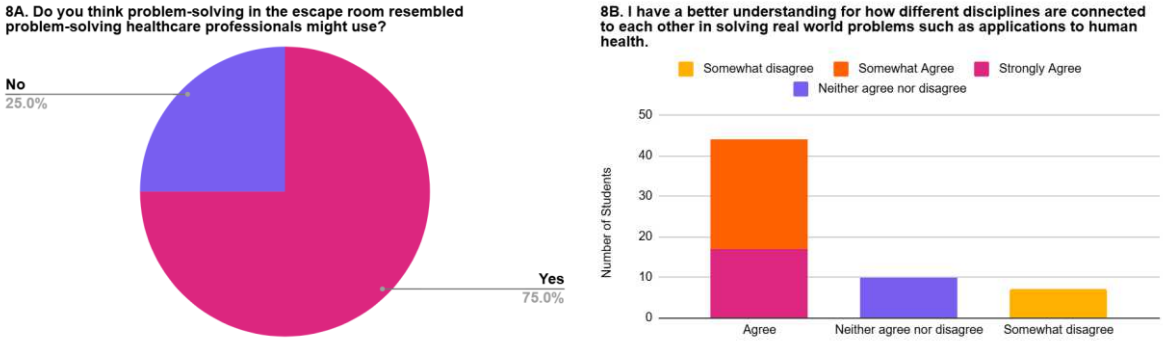


Fig 8 Students Report Connections to Real Life and Other Disciplines After Escape Room

A. Problem-solving within the escape room resembles problem solving health professionals may use. Out of 62 students, 75% indicated that they believed the problem-solving in the escape room resembled problem-solving in healthcare fields

B. Improved understanding of interdisciplinary connections when applying real-world problems. 44 students (n = 62) agreed that they had a better understanding of how different disciplines are connected when solving real-world problems. 27 students strongly agreed and 17 students somewhat agreed with the statement, while only 7 students somewhat disagreed. No students strongly disagreed with the statement

DISCUSSION

Four Pillar Characteristics Define Benefits of Escape Rooms

We designed an educational escape room for a higher education STEM classroom and sought to assess the following possible student benefits: learning gains, increased interest in subject matter, teamwork, leadership, sense of belonging, interdisciplinary connections and real-world connections. Through student surveys, we identified four pillar characteristics associated with their experience participating in the activity. The four pillars are Engagement, Collaboration, Interdisciplinary Connection, and Logic.

In the survey, 91.9% of students reported enjoying the escape room with 77.4% of students agreeing that they would like to see educational escape rooms used more commonly in courses. Students also reported an increased interest in cell biology topics. These findings suggest that students found the activity to be an engaging way to deliver instruction. The findings also suggest that Engagement was a significant aspect of the student experience. Surveys also showed several student testimonials indicating that the Escape Room required them to think critically and apply prior knowledge to successfully complete the activity. Quantitative data indicated a significant increase in quiz scores following the completion of the Escape Room. The mean score increased from 10.3 to 10.9, which indicated actual learning gains took place. The majority of escape room studies have employed attitude surveys, while our study provides a mixed methods approach demonstrating that the perceived learning gains accurately correspond to actual learning gains.

Survey results showed that 72.6% of students expressed that the teamwork aspect of the escape room enhanced their learning experience, which supports Collaboration being an integral part of the escape room experience. Students also shared that they felt the escape room activity was an engaging interdisciplinary activity that was applicable to various fields. This finding suggests Interdisciplinary Connection significantly contributed to the student experience.

The Four Pillars Are Reinforced By Several Frameworks

Active Learning was a crucial student-centered approach used when designing the Escape Room and directly impacted the Engagement pillar. Active Learning is where students are tasked with engaging in higher order thinking tasks like analysis,

synthesis, and evaluation (Bonwell and Eison, 1991). The Escape Room requires students to analyze numerous puzzles and use prior knowledge to solve them. Students had to collaborate, discuss, and actively participate in the activity. Literature shows a connection between active learning in higher education classrooms and an increase in performance (Freeman et al., 2014). We observed that quiz scores increased significantly following the completion of the activity. This supports the finding that the Escape Room activity, an active learning experience, improved performance, and therefore increased actual learning gains.

Game Based Learning (GBL) is an educational framework that uses games to achieve specific learning targets. It is an active learning strategy that requires the students to fully immerse themselves and engage in the activity (Whitton, 2012; Plass et al., 2015). The GBL framework was crucial in the development of an activity that required students to work collaboratively with their teams to complete a series of appropriately challenging puzzles within a specified amount of time.

The Escape Room Collaboration pillar was also designed with Team-Based Learning (TBL) principles in mind. Two key components of TBL are individual and team readiness assurance tests and multiple small groups of students (Parmelee et al., 2012). The Escape Room required small groups of students to begin the activity with a pre-quiz taken individually. Then, the students completed a series of tasks as a group to "escape the room" and solve an overarching problem. To conclude the activity, students took the same quiz again, named the post-quiz, individually. The individual quiz component of this activity held the students accountable for their own progress, while participating in the Escape Room activity encouraged collaboration between students. Data showed that students thought this format strengthened their perception of cell biology concepts while also promoting their individual sense of leadership and sense of belonging.

The four pillar characteristics that were uncovered in student testimonials and ultimately defined the success of this activity employ the Self-Determination Theory. The Self-Determination Theory (SDT) is a psychological framework that explores how three universal needs, autonomy, relatedness, and competence, can impact one's motivation (as reviewed in (Ryan and Deci, 2000). In the Escape Room, the students were given the autonomy to approach solving the puzzles in a way of their choosing. The results of the survey concluded that 72.6% of students felt the Escape Room increased their sense of belonging, which indicates the psychological need for relatedness was met by the experience. The final component of the Self-Determination Theory, competence, could be achieved when students were able to successfully complete each puzzle and "escape" the room. Studies suggest that the successful implementation of the SDT framework can positively impact students' intrinsic motivation, as well as their overall wellbeing (Ryan and Deci, 2020).

We also supported intrinsic motivation development when designing the Interdisciplinary Connection pillar. Many students indicated an intention to pursue

careers in human healthcare or veterinary care following their undergraduate education. Having students assume the roles of epidemiologist and laboratory technician connected to the students' highest level of personal meaningfulness, Identification. Identity-Based Motivation (IBM) occurs when an activity is resonant with an individual's identity (Oyserman, 2007; Oyserman et al., 2017). Our goal was to use interdisciplinary connections to facilitate intrinsic motivation and therefore support the development of self-efficacy in regard to the desired cell biology learning outcomes.

Escape Rooms and a Four Pillar Framework in the Bigger Picture

While this study evaluated the benefits of escape rooms in an undergraduate cell biology laboratory course, the Four Pillars as an educational framework could be easily applied to other fields of study. Any classroom, regardless of field, can apply the framework and established benefits to design and implement an escape room that achieves the learning targets of the designated course. The Four Pillars seek to optimize both learning gains and student satisfaction.

The impact educational escape rooms have on learning outcomes in STEM (especially non-medical) higher education classrooms is not well researched to date. Studies have shown that placing more emphasis on active learning techniques than traditional modes of learning could increase performance, raise average grades by half of a letter grade, and increase total students who complete STEM degrees (Freeman et al., 2014). This indicates that there is a growing need for research on how different active learning strategies can be implemented in higher education classrooms and increase and enhance learning outcomes. The results of this study support findings that claim active learning, GBL, and TBL enhance the learning experience and increase overall learning outcomes. It also helps fulfill the need for more research on how SDT can positively impact learning experience and outcomes in STEM higher education.

Escape Rooms Offer Flexibility and Adaptability

It is important to note that this educational escape room can be customized to fit the specific learning targets and financial capabilities of any program. The difficulty of the puzzles can be tailored to students of all ages to make sure tasks are developmentally appropriate. Topics emphasized in the Escape Room can also be altered to fit the needs of the course. This specific Escape Room was designed for a cell biology course. The Escape Room concept also easily accommodates all budgets. Supplies could range from store bought to handmade. This makes the activity accessible to classrooms of all types. Design of the Escape Room activity took multiple sessions to complete in its entirety. The involvement of the design process could increase or decrease depending upon the desire of the instructor. Set up of the activity

took approximately two additional meetings, but this aspect could also be altered to fit the capabilities of the classroom.

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