Virtual escape room in mathematics

Radosław Baziak
Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, Department of Intelligent Interactive Systems
Email: s180197@student.pg.edu.pl

Tomasz Daruk
Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, Department of Geoinformatics
Email: s171974@student.pg.edu.pl

Karol Żyra
Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, Department of Geoinformatics
Email: s181441@student.pg.edu.pl

Jacek Lebiedź
Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, Department of Intelligent Interactive Systems
Email: jacekl@eti.pg.edu.pl

Dorota Żarek
Gdańsk University of Technology, Mathematics Center
Email: dorota.zarek@pg.edu.pl

Abstract. The project is about developing a virtual reality-based escape room to teach mathematical concepts. The goal was to create an immersive game to engage students in actively solving math puzzles. The research team built the application for use in the Immersive 3D Visualization Lab at the Gdańsk University of Technology and for personal computers. The escape room comprises an introductory room followed by three themed rooms with 13 puzzles total that involve mathematical thinking. To assess the tool's educational impact, the team prepared surveys and plan an experiment with first-year undergraduate participants. Key outcomes delivered were the completed application configured for the target lab and PCs, plus the surveys to quantitatively measure math comprehension before and after students use the escape room. Overall this project combined virtual reality and game design concepts to create an innovative approach for engaging students in learning math concepts in an interactive, visually stimulating setting.

Keywords: Escape Room, VR, Math, Gamification.

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1 INTRODUCTION

We are living in the digital age, which is significantly affecting the younger generation. Young people are looking for answers to various questions on the Internet. The aim of the project is to create an application that will contribute to the development of mathematical skills among young people. The combination of entertainment elements, i.e. a game, or more precisely an escape room, with learning elements in the form of various mathematical puzzles may allow for increased user involvement in the didactic process and, as a result, better learning results.

2 LITERATURE REVIEW

In the SLR process, 3 articles were selected that showed promising value with related topics, these articles are:

- Interactive Laboratories for Science Education: A Subjective Study and Systematic Literature Review [1],
- Escape room dual mode approach to teach maths during the covid-19 era [2],
- Teaching calculus in the first year of an engineering degree using a Digital Escape Room in an online scenario [3].

These sources show that similar experiments have already been carried out, for example in Spain [3], where a group of students was divided in half, with the first part having traditional lessons and the second part having an escape room activity. As a result of these studies, it can be concluded that gamification has a significant impact on students by improving their performance. The most common inconveniences found in the traditional classroom, such as loss of concentration and lack of a visible goal for the student to achieve, are practically negligible in the escape room environment.
In addition to the positive impact on student performance, the literature review also highlights the benefits of the escape room approach in terms of engagement, motivation, and enjoyment [3]. The interactive and immersive nature of an escape room activity creates a fun and stimulating learning environment that encourages students to actively participate and collaborate with their peers. Moreover, the use of digital technologies, such as online escape rooms, provides flexibility and accessibility, allowing students to learn at their own pace and in their preferred setting.
Overall, the findings of the systematic literature review suggest that the use of escape rooms and gamification in education has the potential to revolutionize traditional teaching approaches and enhance the learning experience for students

[2]. As such, educators and institutions should consider incorporating these innovative strategies into their teaching practices to improve student engagement, motivation, and achievement.

3 PROJECT SCOPE

The aim of the project is to develop an application on the Unity platform to present mathematical issues in a virtual reality environment, thus creating an interface between mathematics and the world of modern technology in terms of making teaching mathematics more attractive.

4 BACKGROUND OF THE WORK

4.1 UNITY

Unity is one of the leading game development platforms, that has revolutionised the process of creating applications. It was initially released in 2005 with the aim of making tools accessible to developers of all skill levels. Over the years Unity has evolved into a much bigger system that supports not only game development but also a wide range of interactive media projects, including virtual reality applications.

Unity offers a free license for personal use and projects with small revenue along with compatibility across multiple platforms, as two of it's standout features. The versatility of the technology was crucial for our project as it allowed us to develop an escape room experience that could be easily deployed in our desired CAVE environment. Additionally, it will require little effort to adapt this project for other platforms in the future if the need ever arises.

Version 2019.4.40f1 of Unity was used for this project, which is widely recognized as a stable iteration. Furthermore, this version is compatible with a specific library that enables the integration and synchronization of screen display and control tools that are being used in I3DVL.

4.2 I3DVL

The Immersive 3D Visualization Lab (I3DVL) represents a significant advancement in immersive virtual reality technology [4]. This CAVE system is designed to envelop users in virtual world, offering a high degree of immersion. A typical setup includes multiple large screens, often forming a cube-like space, where stereoscopic images are projected [5]. The user is wearing a pair of special 3D glasses that, in conjunction with position-tracking technology, allow the system to present a virtual environment from the correct perspective, adjusting in real time as the user moves and looks around. This solution creates a highly convincing illusion of physical presence within the virtual space.

One of the key features of this system is reduced motion sickness. The stationary nature of CAVE and the constant visibility of one's own body reduces the likelihood of motion sickness compared to traditional VR headsets.

Another advantage of using CAVE in the context of virtual escape rooms is the ability to create a space that corresponds in size to real rooms. This allows participants to move naturally in the virtual environment, which greatly enhances the immersion and realistic experience. In addition, another important aspect of using CAVE in virtual escape rooms is the ability for participants to collaborate and interact in the virtual space. Unlike traditional VR systems, where interactions between users are often limited to communication via avatars, CAVE allows participants to be physically present in the same space. This allows for natural non-verbal communication, collaboration and team building, which is crucial in the context of solving puzzles in escape rooms.

By utilizing the unique capabilities of the I3DVL system, our VR escape room project aimed to create an innovative, engaging and effective learning environment. The project explored how immersive VR technology, specifically in a CAVE setup, can enhance the educational experience, offering insight into the future of interactive learning and the potential of VR in education.

5 PUZZLES DESCRIPTION

All puzzles are divided between three rooms that can be achieved from lobby in no particular order. After entering a room player has to finish all riddles to escape. Each room contains four or five different puzzles.

5.1 Egyptian room

Puzzle 1 The puzzle involves marking the results of complex number operations on the board. Complex numbers are displayed in the complex plane. The player must perform operations on these numbers and mark the result on the plane. Appropriate marking of all tasks given in sequencial order is necessary to complete the room.

Puzzle 2 On the wall there is a system of three equations with three unknowns, the solution of which is the code to the cipher. To help the participant solve the system, a mechanism is available that allows us to manipulate each of the equations. The mechanism allows you to add and subtract equations with each other or multiply and divide the equation by a constant.

Puzzle 3 A cube grid is painted on the wall and next to it is a hole. There are cubes scattered across the floor. The goal is to place the correct cube into the grid and insert it into the hole.

Puzzle 4 The puzzle involves playing with vectors, a coordinate system is visible on the wall, with a black dot marked on it. Dropping any of the plates scattered around into the hole next to it causes the dot to move by a given vector, the aim being to bring the dot into the coordinates given above the plane.

5.2 Modern room

Puzzle 1 There is a scale in the room with an object of unknown weight on one of the arms. Nearby there are blocks in the shape of Roman numerals and their weight corresponds to the value of the number. By placing appropriate blocks on the scale it brings the balance. Weight of the block is a code for the puzzle.

Puzzle 2 Calculate the mixed product of three vectors placed in a three-dimensional grid. Vectors can be freely modyfied in given range using buttons nearby grid. Calculating the mixed product amounts to calculating the determinant of the matrix. The solution to the puzzle is the key to the cipher.

Puzzle 3 There is an object in the room that consists of three sliders placed on the axes of the coordinate system, the position of the sliders determines the position of the plane which equation is above. In the first step, the sliders must be moved so that the plane corresponds with the one on the equation. Once this step is successfully completed the sliders will automatically move to new positions and lock, reading the parameters of the newly created plane is the key to the cipher.

Puzzle 4 There is a whiteboard in the room where we can draw any shape we want. The aim of the puzzle is to draw the graph of the function displayed next to the board sequentially for three different functions.

5.3 Workshop room

Puzzle 1 The numbers from Fibonacci sequence are written on the wall. Four randomly selected digits are blurred. Correctly guessing these numbers creates a combination to solves the puzzle.

Puzzle 2 There is a pipe in the room against a background of two coordinate systems, with a complex equation written above each system. At the centre of these systems there are spaces for a dial. Different knobs are found scattered around the room and each has markings on it in the form of red dots symmetrically placed on their rim. In order to solve the puzzle, you must place the correct dial in each arrangement with correct rotation so that the dots on its rim coincide with the solutions of that particular complex equation.

Puzzle 3 A puzzle replicating Horner's diagram. There are 4 empty spots on the wall. Above them are written the coefficients of a third degree polynomial, in order from highest degree to lowest. One the left there is a number filling the first step in solving the division using Horner's scheme. The player must place correct blocks found in the room in empty spots.

Puzzle 4 A puzzle involving addition of binary numbers. The result to be calculated is recorded by pressing buttons available under the stored operations represented by light bulbs. The results obtained must then be converted into decimal numbers. Combining these results produces a cipher, which must be entered using the available numeric keypad.

Puzzle 5 Large numbers and signs are drawn on the two parallel walls, floor and ceiling of the room, and there is also a padlock at the '=' sign for a cipher. The puzzle is to associate the structure of the room with the functions of the ceiling and floor in mathematics.

6 APPLICATION DESIGN

6.1 Implementation

The structure of the application underwent changes during development due to encountered obstacles and the knowledge gained from implementing certain elements of the escape room.

The application was originally designed to be split, with each room was on a separate stage and control of the gameplay was held by the Game Manager. During testing, it was discovered that this caused issues with the correct synchronisation of the player's position and the collection of input data from the controller during scene changes. As a result, we made the decision to place the entire solution on one main scene.

To aid application development, directives were used to seperate functions between those intended exclusively for the I3DVL target environment and the Windows development environment. This ensured that the appropriate code fragments were used for each platform.

The application's most crucial components are classes:

- GameManager - the gameplay manager, this class is always active and deals with issues related to more than one room. These include managing transitions between rooms, storing variables and flags that must be accessed at any time during the life cycle of the application, supporting the control system,

handling the measurement of time spent in rooms and managing rooms (actions like reset and rotate). This class also contains globally needed enums, such as RoomID.

- Raycaster - this class is responsible for supporting the handling of the controller held by the player in I3DVL. Its purpose is to transmit the ray coming out of the held device to trigger the appropriate events and actions on the objects we are targeting. The main mechanic relies on filtering the layers of objects 'hit' by the ray in order to distinguish them.

- Interactive - this class serves as a base class for other classes (e.g. Pickable) and can also be directly assigned to selected objects. It is assigned to all interactive objects and allows you to define their behaviour such as highlighting them to indicate the possibility of interaction.

- Pickable - a class inheriting from the Interactive class, its purpose is to enable the lifting action of a given object to which it is assigned and to define related elements such as limiting the movement of an object along given axes, managing their rotation and the influence of gravity.

The rest of the classes are dedicated to the corresponding objects and puzzle elements.

6.2 Graphics design

To achieve the desired design no typical rendering pipelines were used, such as High-Definition Render Pipeline and Universal Render Pipeline. Due to the simplicity of the design, it also did not require the use of any shaders. Most of the graphical assets and textures were obtained from Unity Asset Store or other open-source asset websites. Some assets required individual editing and adjustment using additional software such as Blender and other graphics editors to meet the project's initial requirements.

Thanks to the obtained and created assets, it was possible to create four separate unique-looking rooms. The first of the rooms, the lobby, resembles a traditional, slightly childish-looking classroom (Fig. 1). It contains only four pupils' desks and one teacher's desk due to space constraints imposed by I3DVL dimensions. It also contains additional decor elements such as bookshelves, cubicle shelves, blackboard, and other small decorations. The second room resembles an ancient Egyptian temple in the middle of the desert (Fig. 2). It contains multiple small pyramids, sphinx, and other assets using different sand-like textures. The third of the rooms resembles an old mechanic's workshop (Fig. 3). It contains different mechanical tools such as drills, hammers, paints, and other decor elements. The last of the rooms resembles a modern futuristic space (Fig. 4). All of the aforementioned spaces contain puzzles described in the previous chapter.

Fig. 1. Room 'Lobby' in CAVE

Fig. 2. Egyptian room

Fig. 3. Workshop room

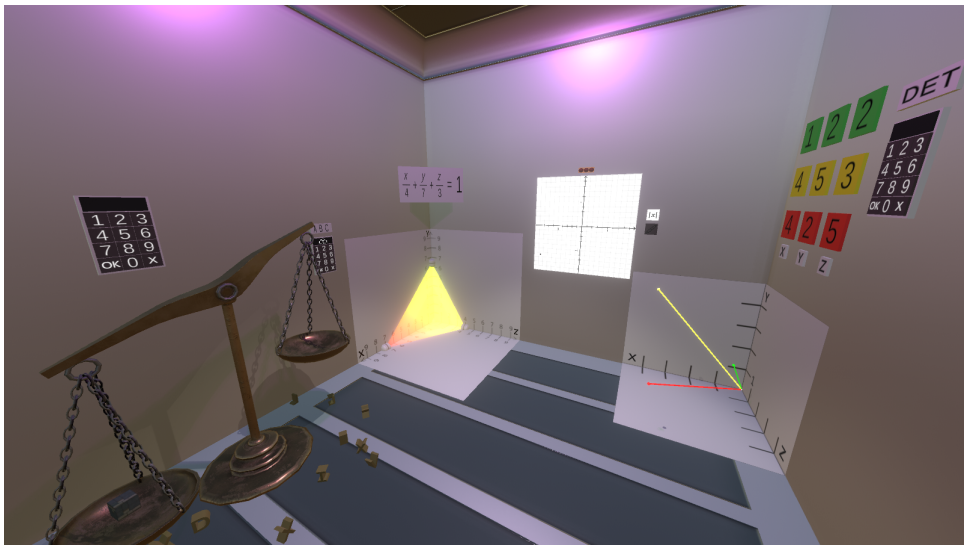

Fig. 4. Modern room

6.3 Additional information

Rotation of the rooms - In order to enable gameplay in an I3DVL environment without the need to lock oneself inside, i.e. in our case leaving one of the walls open, the possibility to rotate the room by a multiple of 90 degrees has been implemented in rooms that require this option to complete all puzzles.

7 RESEARCH SURVEYS

7.1 SURVEY DRAFT

During the course of the study, four surveys were conducted, comprising two assessments related to well-being and two assessments focused on knowledge. At the start of the experiment, each participant was obligated to fill out a comprehensive well-being survey. Subsequently, they proceeded to complete a knowledge-based survey concentrating on mathematical concepts. Following the experimental phase, participants were presented with a satisfaction survey to assess their well-being subsequent to the experiment. Furthermore, a second knowledge assessment survey was conducted to evaluate participants' comprehension after the study.

Well-being Survey The survey aimed to collect vital information from participants, focusing on key demographic variables, including their gender, age, and educational background. Additionally, a balanced scale was employed for the formulation of five survey questions.

1. How would you assess your overall well-being?
2. How would you rate your current level of fatigue?
3. How do you evaluate your current level of concentration?
4. How do you assess your current stress level?
5. How do you rate your mathematical abilities?

Two open-ended questions were incorporated into the survey to solicit qualitative responses from participants. These questions were designed to capture nuanced insights beyond quantitative measures.

- How would you describe your current mood in a few words?
- Concluding remarks.

Knowledge Survey This survey, designed for knowledge assessment, involved participants providing their unique student identification numbers for effective data correlation with other surveys. Consisting of 11 single-choice questions and one fill-in-the-blank question, the survey was administered twice – once before the study and once afterward. It is important to note that the two instances of the survey collected distinct sets of data.

1. Provide the sum of the complex numbers.

2. Indicate the result of subtracting complex numbers.
3. What is the equation after certain operation?
4. Specify the formula for the function visible in the image.
5. Specify the formula for the function visible in the image.
6. Identify the degree of the complex number root.
7. Point out the illustration depicting provided root of a complex number.
8. Calculate the mixed product of three vectors.
9. Provide the values of x, y, z for which the plane with the equation intersects with the axes.
10. Provide the parameters A, B, and C for the plane shown in the image.
11. Utilizing the Horner's method, divide the polynomial $W(x)$ by $P(x)$.
12. Specify the remainder when dividing the polynomial $W(x)$ by $P(x)$.

Satisfaction Survey This survey includes a section for participant indices, facilitating data organization and analysis. Comprising 10 questions formulated on a balanced scale, participants were prompted to rate their satisfaction levels. Additionally, the survey incorporated five open-ended questions, allowing respondents to provide qualitative insights and elaborate on their experiences. This dual-format survey, presented in two similar versions—one for participants engaged in traditional board-based activities and the other for those experiencing the escape room.

1. How would you rate your overall well-being after the experiment?
2. How do you assess your level of fatigue after the experiment?
3. How do you evaluate your level of focus after the experiment?
4. How do you assess your stress level after the experiment?
5. How would you rate your mathematical abilities after the experiment?
6. Are you satisfied with your participation in the Mathematical Escape Room / conducted activities?
7. To what extent did you find the presented puzzles / tasks / knowledge understandable?
8. Have the activities improved your level of mathematical knowledge?
9. Could the Mathematical Escape Room / activities be improved?
10. If so, in what way?
11. Did you enjoy the Mathematical Escape Room / conducted activities?
12. What did you like about it?
13. What didn't you like?
14. How would you describe your mood after the experiment in a few words?
15. Final Remarks.

7.2 STUDY GROUP

The study group consisted predominantly of first-year computer science students from Gdańsk University of Technology, complemented by participants from the third-year Computer Science and first-year Mechanical Engineering, affiliated with the University of Applied Sciences in Elbląg (Fig. 6). This diversification

aimed to encompass varying academic backgrounds and perspectives within the study. The group also featured a balanced representation of both male and female participants (Fig. 5). Notably, 54 individuals engaged in the escape room experience, while 9 partook in traditional board-based activities.

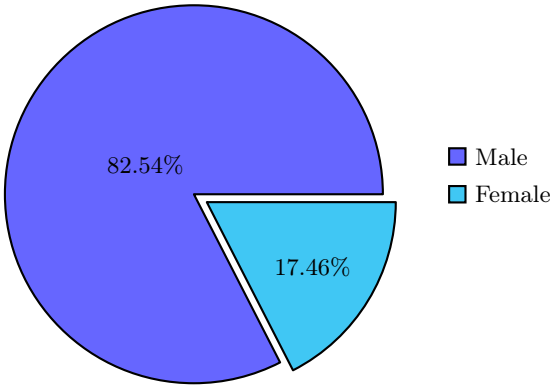

Fig. 5. Gender distribution in the study group.

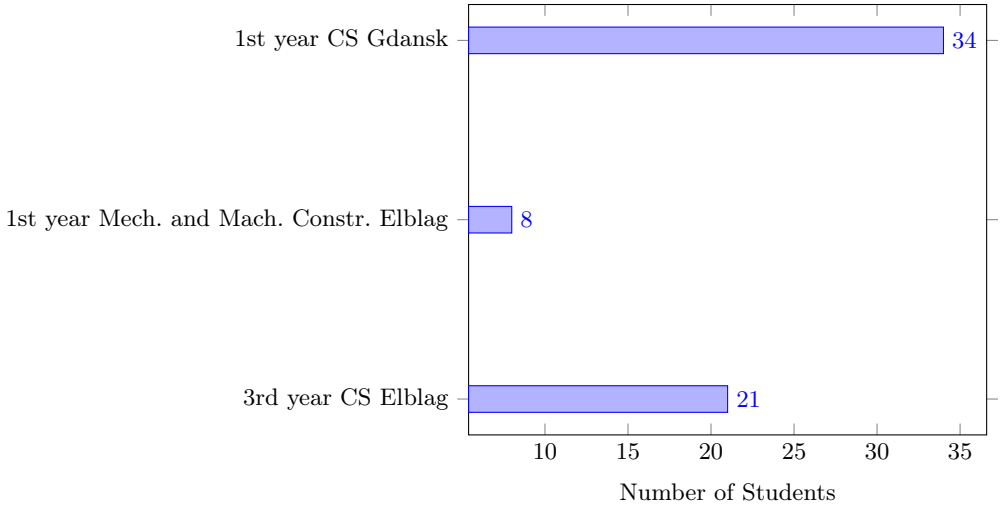

Fig. 6. Number of students in different programs and locations.

8 OBSTACLES AND DIFFICULTIES

The research journey presented several challenges that merit thoughtful consideration as they may have influenced the outcomes of the study. This section delves into the encountered obstacles, offering a nuanced perspective on their potential impact on the research findings.

1. **Group Dynamics in Escape Room Setting:**
   - The collaborative nature of the Escape Room study introduced complexities in group dynamics. Notably, not all participants were uniformly engaged in problem-solving tasks, leading to variations in individual contributions and problem-solving approaches.
2. **Time Constraints in Escape Room Experiment:**
   - The experiment operated within defined time constraints, posing a challenge to groups striving to complete tasks. The restricted time frame may have impacted the extent to which groups could unravel and solve all the presented puzzles.
3. **Incomplete Survey Responses:**
   - Certain survey responses became invalid due to incompleteness or missing data, introducing an element of unpredictability into the dataset. Instances occurred where entire surveys were disregarded due to essential information being absent.
4. **Varied Difficulty Levels in Knowledge Surveys:**
   - Discrepancies in the difficulty levels of knowledge surveys were identified. The post-study survey, in particular, may have presented questions of slightly elevated complexity compared to the pre-study knowledge assessment, potentially affecting the evaluation of knowledge retention.
5. **Temporal Disparities Between Experimental and Control Groups:**
   - The control group, engaged in traditional board-based activities, had a more extended duration of approximately 2 hours. This temporal asymmetry between the experimental and control groups could have influenced the depth and intensity of their respective learning experiences.

9 RESULTS

The assessment of emotional states before and after both tabletop exercises and the Escape Room activity (Fig. 7) revealed a noteworthy trend. Following the tabletop exercises, a few participants marked their emotional state as "bad," a deviation from their pre-exercise feelings. However, the most striking observation was the substantial increase in positive emotional states after the Escape Room activity. Many participants reported feeling significantly better, emphasizing the positive impact of the Escape Room experience on their overall well-being.

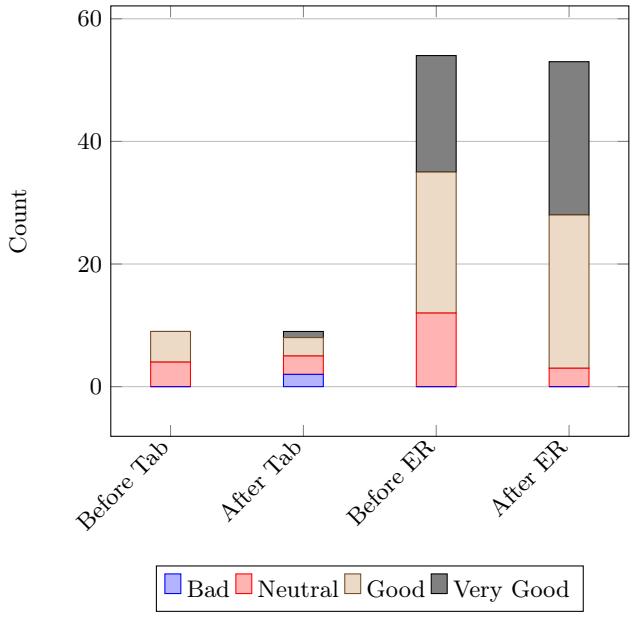

Fig. 7. Emotional State Comparison Before and After Interventions.

The examination of knowledge test outcomes before and after the study uncovers discernible trends. Initially, participants demonstrated a certain level of knowledge, with a subsequent notable increase observed following the completion of tabletop exercises (Table. 1). This augmentation is evident in the average knowledge scores, which elevated from the initial state.

Similarly, prior to the Escape Room activity, participants displayed a distinct level of knowledge, and post-activity assessments indicated a discernible positive shift. The post-activity average knowledge score experienced a slight increase, reaffirming the impact of the Escape Room intervention on participants' knowledge levels (Fig. 8).

	Average	Standard Deviation
Before T	6.889	2.147
After T	9.667	1.414
Before ER	8.389	1.687
After ER	9.000	1.682

Table 1. Average and Standard Deviation for Knowledge Test.
T - Tradicional classes, ER - Escape Room

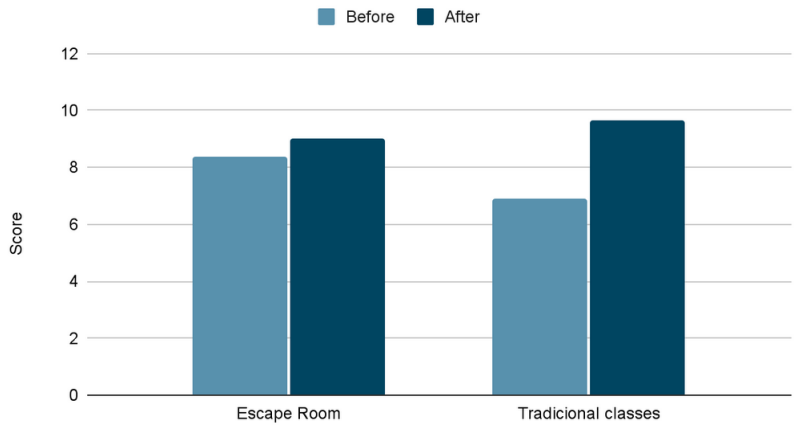

Fig. 8. Average score for Knowledge Test

In the qualitative analysis of open-ended questions following the Escape Room activity, a prevalent theme emerged among many students. A substantial number of participants expressed a heightened sense of focus, relaxation, engagement, and satisfaction. The responses indicated that the Escape Room experience not only stimulated interest but also fostered a positive and relaxed learning environment.

This recurrent theme underscores the multifaceted impact of the Escape Room intervention, extending beyond traditional knowledge assessment. The students' subjective experiences suggest that the activity not only contributed to cognitive engagement but also positively influenced their overall emotional well-being during the learning process.

10 CONCLUSION

The results indicate a significant positive effect on participants' emotional states and knowledge scores following both the tabletop exercises and the Escape Room activity. Notably, the post-activity assessments revealed a higher level of satisfaction and relaxation among individuals who experienced the Escape Room.

1. **Disparities in Group Sizes:** It is crucial to acknowledge the disparities in the sizes of the control and experimental groups. The control group, engaged in tabletop exercises, had a smaller participant pool compared to the Escape Room group. This disproportion should be considered when interpreting the findings.
2. **Time Constraints in Escape Room Activity:** Participants in the Escape Room group faced time constraints, limiting their ability to fully engage with the tasks. This restriction may have influenced the observed outcomes, emphasizing the need for balanced time allocations across interventions in future studies.

3. **Satisfaction and Relaxation Post Escape Room:** Post Escape Room, a notable increase was observed in the number of participants reporting feelings of satisfaction and relaxation. This suggests that the immersive and collaborative nature of the Escape Room contributed positively to the participants' emotional well-being.
4. **Consideration for Future Research:** Future research could benefit from incorporating a control group without any additional activities, solely undergoing knowledge tests before and after the study. This would allow a more nuanced comparison to ascertain whether the Escape Room itself provides superior results in mathematical learning.
5. **Leveraging Escape Room for Collaboration and Learning Disabilities:** The project's Escape Room design holds potential for exploring collaborative dynamics among participants. Additionally, given the reported calmness and relaxation, it could be explored as a tool for studying the learning capabilities of individuals with conditions such as ADHD. This avenue may provide insights into alternative learning approaches for diverse student populations.
6. **Context of Participants' Mathematical Background:** Considering that participants had completed a mathematics course during their studies, it is important to acknowledge that a substantial portion of their knowledge might stem from these prior academic experiences. This contextual background should be taken into account when interpreting the observed knowledge outcomes.

In conclusion, while the study sheds light on the positive impact of experiential learning, further research incorporating the outlined considerations is recommended for a more comprehensive understanding of the potential benefits and nuances associated with such interventions.

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