Virtual Escape Room in Mathematics

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Abstract

The paper presents 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. 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 planed an experiment with students. Key outcomes delivered were the completed application configured for the target lab, 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, virtual reality, mathematics education, gamification.

1. Introduction

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, as shown by the surveys we conducted.

2. Literature review

The popularity of escape rooms among young people has resulted in educators' interest in this type of solutions. Therefore, various types of educational games based on the concept of an escape room began to be created and researched. However, while entertainment mainly concerns physical (real) escape rooms, educational escape rooms are developed as computer tools [1, 16]. Sometimes they are used for phobia therapy [14] or memory

training [4], but most often, they are thematic and concern specific school subjects such as language [2], biology [11, 12], physics [13], chemistry [7], and also mathematics [5, 6, 8, 10, 13, 15]. Escape rooms often take the form of a video game designed for smartphones or PCs, in which the user participates in the game via a 2D screen [5, 10, 13, 15]. We would call such games digital escape rooms [15]. However, games using immersive virtual reality (VR), which could be called virtual escape rooms [15], seem more attractive. They most often use VR headsets [4, 7, 12], but virtual reality CAVEs (Cave Automatic Virtual Environment) are also used [3, 9, 17]. The advantage of a CAVE is the possibility of simultaneous participation of several students in a way similar to playing in a physical escape room - seeing each other and solving puzzles together.

Research on the effectiveness of educational escape rooms involves dividing students into two equal groups [10]. The first group has traditional lessons and the second one has an escape room activity. 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 rooms. Benefits of this approach in terms of engagement, motivation, and enjoyment are very important [10]. 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 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 [15]. As such, educators and curriculum designers should consider incorporating these innovative strategies into their teaching practices to improve student engagement, motivation, and achievement. Thanks to this, their work would be more effective and satisfying. Therefore, this solution should be considered beneficial for all stakeholders.

3. Project conditions

The aim of the project was 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 at the level of the first year of engineering studies more attractive. 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.

The Immersive 3D Visualization Lab (I3DVL) represents a significant advancement in immersive virtual reality technology [9]. 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. 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 cybersickness. The stationary nature of a CAVE and the constant visibility of one’s own body reduces the likelihood of cybersickness compared to traditional VR headsets. Another advantage of a CAVE in the context of virtual escape rooms is the ability to create a space that corresponds in size to physical rooms. This allows participants to move naturally in the virtual environment, which greatly enhances the immersion and realistic experience. Another important aspect of a CAVE is the ability for participants to collaborate and interact in the virtual space. Unlike traditional VR headsets, where interactions between users are often limited to communication via avatars, a 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 lab, our VR escape room project aimed to create an innovative, engaging and effective learning environment. It 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.

All puzzles are divided between three rooms that can be achieved from **lobby** in no particular order (Figure 1). The lobby resembles a traditional, slightly childish-looking classroom with three doors leading to puzzle rooms. After entering a puzzle room players have to finish all riddles to escape. Each such room contains 4-5 different puzzles.

The **Egyptian room** resembles an ancient Egyptian temple in the middle of the desert. It contains multiple small pyramids, sphinx, and other ancient assets. There are four puzzles in it: complex number operations, solving a system of three linear equations by row reduction, fitting the cube net, addition of 2D vectors. The **modern room** is characterized by contemporary decor. It resembles a modern futuristic space. There are four puzzles in it: Roman numerals, calculating the mixed product of three 3D vectors, determining the 3D position of a plane based on its equation, drawing the graph of the given function. The **workshop room** resembles an old mechanic's workshop. It contains different mechanical tools such as drills, hammers, and paints. There are five puzzles in it: Fibonacci sequence, solving the complex equation $z^n = \pm 1$, division of polynomials using Horner's scheme, addition of binary numbers, floor and ceiling functions.

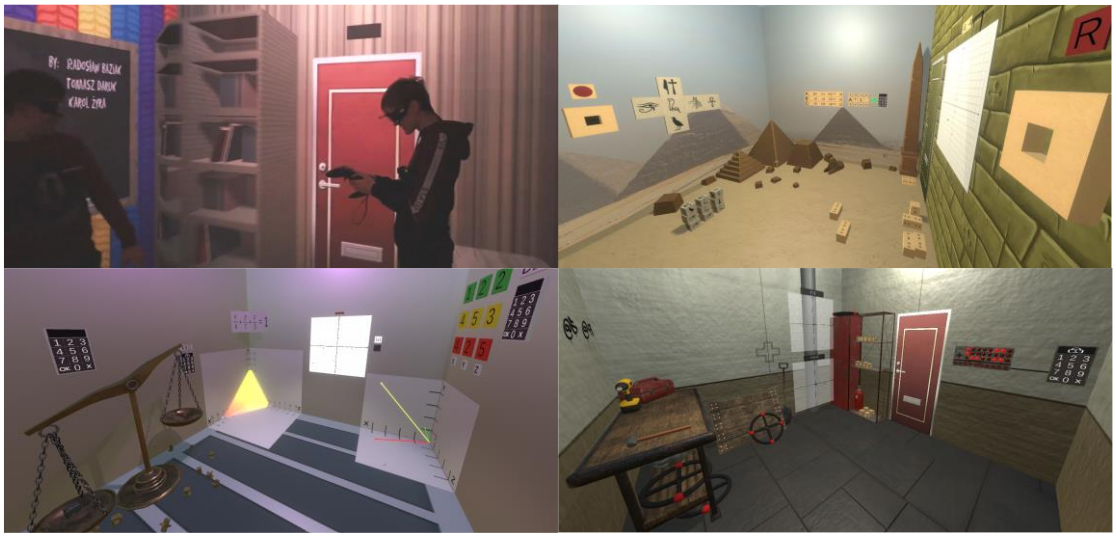

Fig. 1. Lobby (top left), Egyptian (top right), modern (bottom left) and workshop (bottom right) rooms.

4. Experiment

During 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 and 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.

The **well-being survey** aimed to collect vital information from participants (gender, age, education etc.). Additionally, a five-point scale was employed for the formulation of five survey questions about well-being. Two open-ended questions were incorporated into the survey to solicit qualitative responses from participants. The **knowledge survey**, designed for knowledge assessment, involved participants providing their unique student identification numbers for effective data correlation with other surveys. Consisting of 12 tasks: 11 single-choice questions and one fill-in-the-blank question, the survey was administered twice –before the study and afterward. The **satisfaction survey** includes a section for participant indices, facilitating data organization and analysis. Comprising 10 questions formulated on a five-point 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.

The study group of 54 men and women consisted predominantly of first-year Computer Science students from the Gdańsk University of Technology, complemented by participants from the third-year Computer Science and first-year Mechanical Engineering from the University of Applied Sciences in Elbląg (Fig. 2). This diversification aimed to encompass varying academic backgrounds and perspectives within the study.

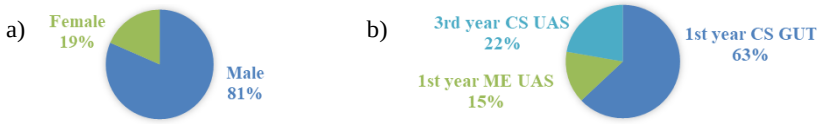

Fig. 2. Gender distribution among students (a), percentage of students from given fields and universities (b).

There are several challenges worth noting that merit thoughtful consideration as they may have influenced the outcomes of the study. Not all participants were uniformly engaged in problem-solving tasks, leading to variations in individual contributions and problem-solving approaches. The restricted time frame may have impacted the extent to which groups could unravel and solve all the presented puzzles. Certain survey responses became invalid due to incompleteness or missing data. Furthermore, we have concerns that the post-study survey may have presented questions of slightly elevated complexity compared to the pre-study knowledge assessment. To sum up, the results presented below should be treated as pilot results that indicate the direction of further research, especially in the context of comparing the increase in knowledge.

5. Results

The assessment of emotional states before and after escape room activity revealed a noteworthy trend (Fig. 3a). The most striking observation was the substantial increase in positive emotional states after the escape room activity. Many users reported feeling significantly better, emphasizing the positive impact of the escape room experience on their overall well-being. 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.

The examination of knowledge test outcomes before and after the study uncovers discernible trend. Initially, participants demonstrated a certain level of knowledge, with a subsequent increase observed following the completion of escape room exercises. This augmentation is evident in the average knowledge scores (Fig. 3b), which elevated from the initial state. The post-activity average knowledge score experienced a slight increase, reaffirming the impact of the escape room intervention on participants' knowledge levels.

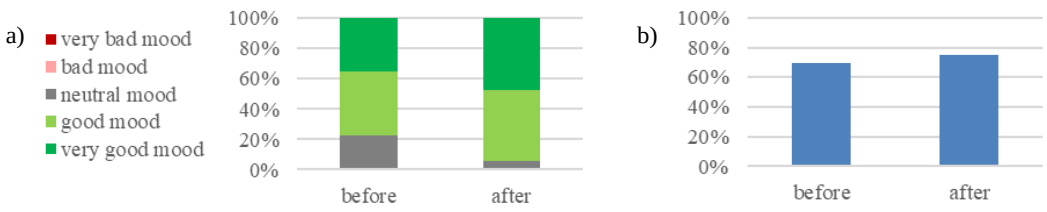

Fig. 3. Emotional state (a), percentage of correctly solved knowledge tasks (b) before and after escape room.

6. Conclusion

The results indicate a significant positive effect on participants' emotional states and knowledge scores following the escape room activity. Notably, the post-activity assessments revealed a higher level of satisfaction and relaxation among individuals who experienced the escape room. Even though students did not express major objections about the puzzles, improving some of them could probably increase this effect (e.g., it was difficult for students to precisely draw a graph of a function using a hand-held controller). The conducted research does not explain all aspects of using an escape room. The authors plan further research, during which attention should be paid to the comparison of the effectiveness and satisfaction of a CAVE-based virtual escape room with typical classroom activities, as well as with a digital and headset-based virtual escape rooms. Another direction for future research will be the leveraging escape room for collaboration and learning disabilities. 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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