# Educational values of a virtual escape room in mathematics

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**Abstract**

The paper presents research on the increase in mathematical knowledge of students using a specially implemented, deeply immersive and highly engaging virtual escape room based on mathematical puzzles. It was built under the supervision of the authors for use in a CAVE-type installation in the Immersive 3D Visualization Lab at the Gdańsk University of Technology. The virtual escape room comprises an introductory room followed by three themed rooms with 13 puzzles total that involve mathematical thinking. To assess the educational impact of the escape room, an experiment was conducted with students starting their first year of technical studies. The experiment consisted of solving mathematical puzzles in the escape room by cooperative teams of 2-5 students, preceded and followed by satisfaction surveys and knowledge tests. Each group also participated in classroom lesson, some before visiting the escape room and others after. The greatest increase in knowledge was achieved for classroom lessons, followed by the escape room.

**Keywords: escape room, virtual reality, mathematics education, gamification.**

## 1. Introduction

Our previous research on a virtual escape room in mathematics [3] showed a significant 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 fettle. Knowledge tests conducted before and after the study also revealed a slight increase in knowledge levels, confirming the impact of the escape room intervention on the participants' knowledge levels. However, we decided to check the level of knowledge growth more precisely, while also monitoring the level of satisfaction with solving puzzles in the escape room. This paper is therefore a deepening of research conducted a year ago [3] and its aim is to evaluate the educational value of the virtual escape room in mathematics designed to develop students' mathematical skills.

## 2. Literature review

The popularity of escape rooms among students is noticed by educators who have been using this type of solution in education for over a dozen years. As a result, various types of educationally oriented escape rooms have been developed and tested. While traditional entertainment escape rooms are usually real objects, educational escape rooms are most often computer tools [1], [18]. Educational escape rooms are mostly thematic and related to school subjects: a foreign language [2], chemistry [8], biology [13, 14], physics [15], and mathematics [3], [6, 7], [9], [11, 12], [15], [17], [19]. However, there are also those designed for phobia therapy [16] or memory training [4]. Regardless of the type of educational escape room, all publications indicate the high educational potential of this solution and criticize the conventional classroom approach to teaching [17]. It is often emphasized that escape rooms develop teamwork and communication skills [11], [19].

Educational escape rooms are divided into two categories. The digital escape rooms are video games developed for smartphones or PCs, where the user participates in the

game via a 2D screen [6], [12], [15], [17], [19]. Virtual escape rooms, on the other hand, are games that use immersive virtual reality devices such as VR headsets [4], [8], [14] or CAVE-type installations (Cave Automatic Virtual Environment) [5], [10], [20]. The advantage of the CAVE is that several students can participate simultaneously in a way similar to playing in a real escape room: seeing each other and solving puzzles as a team.

## 3. Virtual escape room

The CAVE type installation in the Immersive 3D Visualization Lab (I3DVL) is a device that provides several people with deep immersion in virtual reality at the same time [10]. Being there is not really any different from being in a traditional physical escape room. Participants can see the puzzles, see each other, talk to each other, and even touch each other. In our virtual escape room [3], all the puzzles are spread across 3 rooms that can be accessed from the lobby in any order. The lobby looks like a classic classroom with three doors that lead to puzzle rooms. Each room contains 4 to 5 different math puzzles.

In the ancient Egyptian style room there are 4 puzzles: complex number operations, solving a system of 3 linear equations by row reduction (Fig. 1 a), addition of 2D vectors, fitting the cube net. The modern room contains 4 puzzles: calculating the mixed product of three 3D vectors, drawing the graph of the given function, determining the 3D position of a plane based on its equation (Fig. 1 b), Roman numerals. The workshop room offers 5 puzzles: Fibonacci sequence, solving the complex equation $z^n = \pm 1$, addition of binary numbers, division of polynomials using Horner's scheme, floor and ceiling functions.


**Fig. 1.** Virtual escape room: students in Egyptian (a) and modern (b) rooms (photo Robert Trzosowski).

## 4. Experiment

To test the educational effectiveness of escape rooms, students are usually divided into 2 equal groups with similar intellectual potential [12]. The former group participates in a conventional classroom lesson, while the latter solves puzzles in an escape room. However, we decided to check whether combining both types of activities (classroom lesson and escape room) would bring additional educational benefits. We therefore offered the former group, who had already completed a lesson in the classroom, a visit to a virtual escape room, and the latter group, who had completed the escape room, a conventional lesson in the classroom. The results surprised us.

The study involved 3 first-year student groups before they began the mathematics course: 2 *Geodesy and Cartography* groups: *G&C* 1 (9♀, 3♂), *G&C* 2 (3♀, 5♂), and 1 *Recycling and Energy Recovery* group *R&ER* (8♀, 2♂). Groups *G&C* 1, *R&ER* began the experiment with the escape room, then a few days later they took part in a classroom lesson, 3rd group participated first in a classroom lesson and 3 days later in the escape room.

During the two-stage study (escape room and classroom lesson or classroom lesson and escape room), 6 surveys were conducted, comprising 2 assessments related to fettle before and after escape room activity and 4 knowledge tests before and after both activities. The fettle assessment included questions on a five-point scale (1 – very negative, 2 – negative, 3 – neutral, 4 – positive, 5 – very positive) regarding the following aspects: well-being, rest level, concentration, relaxation, assessment of mathematical abilities, and mood. The knowledge tests included 12 mathematical tasks (11 single-choice questions and one fill-in-the-blank question), each worth 1 point, with two pairs of

tasks on the same topic being worth 0.5 points. The maximum number of points was therefore 10. All mathematical surveys are similar to each other and are designed to assess changes in participants' knowledge throughout the experiment.

## 5. Results

Fig. 2 a, c, e show the emotional states before (■) and after (■) the activity in the escape room, which generally increase positive emotional states. Users emphasized the escape room experience had the positive impact on their well-being, concentration, relaxation and mood while the rest level and sense of mathematical ability remain unchanged. The results are of course in line with expectations and also with previous studies [3].

Analysis of knowledge test results in subsequent stages of the study presented in Fig. 2 b, d, f reveals less obvious relationships. Students who started the experiment with an activity in the escape room initially demonstrated a knowledge level of 67% (■). After this activity, the level of knowledge increased by several to a dozen or so percentage points (■). After a few days break, the level dropped only for the field *R&ER* (■), to reach 70% after the classroom lesson (■), only 3 percentage points more than the initial level of knowledge. The situation was different for students who started the experiment with classroom lesson. For unknown reasons, their initial level of knowledge was lower and amounted to 53% (■). After the classroom lesson, it increased by 13 percentage points (■). After a three-day break, before entering the escape room, their level of knowledge was again higher by 13 percentage points (■). After the activity in the escape room this level increased again, although only by 5 percentage points (■). The total increase in the level of knowledge was therefore 31 percentage points (10 times more).

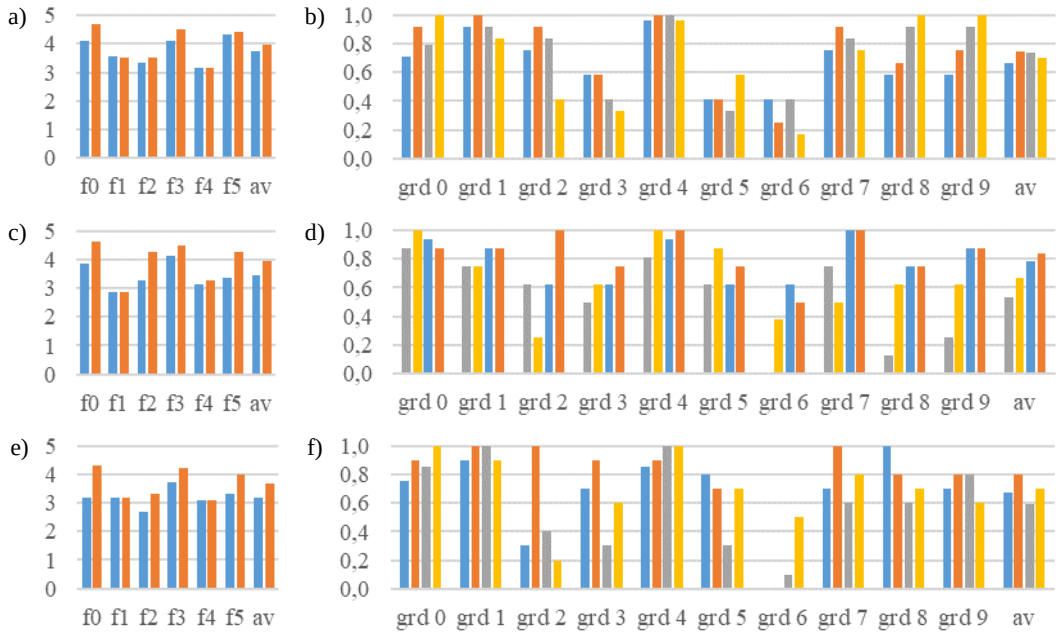


**Fig. 2.** Fettle assessment before and after the escape room activity for groups *G&C* 1 (a), *G&C* 2 (c) & *R&ER* (e): f0 – well-being, f1 – rest level, f2 – concentration, f3 – relaxation, f4 – math abilities, f5 – mood, av – avg. score. Knowledge tests results before and after the escape room activity and classrooms lessons for groups *G&C* 1 (b), *G&C* 2 (d) & *R&ER* (f): grd *k* – grade for task *k*, av – average grade. Meaning of colors: ■ – before escape room, ■ – after escape room, ■ – before classroom lesson, ■ – after lesson.

## 6. Conclusion

The results show the positive impact of escape room activity on well-being, concentration, relaxation and mood, but no effect was noted on the rest level and sense of mathematical ability. More interesting results concern changes in students' knowledge. All groups noted an improvement in average knowledge test scores after visiting the escape room (■ vs. ■). The largest increase was observed in groups that started the

experiment with an escape room. However, a test a few days later, before the classroom lesson, showed some decline in knowledge (■). Moreover, the classroom activities failed to restore the level of knowledge gained after the escape room activity (■). Completely different results were for the group that began the experiment with classroom lesson and ended it with activity in the escape room. There has been continuous growth here. The relatively small increase after the escape room activity can be explained by the relatively high level of knowledge recorded before that activity. The results showed that an escape room itself does not guarantee the durability of knowledge, but it is an excellent tool for consolidating and deepening the knowledge previously acquired during classroom lesson.

Puzzles in our escape room (as well as the accompanying classroom lessons) concern different areas of mathematics. It means that the gained knowledge was scattered across topics. Therefore, we plan to develop a new single-topic escape room (e.g. for matrix operations only) and repeat the research described here. This will correspond directly to a typical single-topic classroom lesson, so the comparison may yield more practical results.

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