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Physics Escape Room as an Educational Tool

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Abstract. Escape rooms have flourished in the last decade. These are adventure games in which players work together to solve puzzles using hints, clues and a strategy to escape from a locked room. In many cases they use different phenomena related to physics. Hence the idea of using escape rooms in science centers or even in classroom activities. Escape rooms are designed for one single team of players, the method is more suitable for activities in a science centre. In our paper, we show that escape rooms' puzzle solving methods could be used in physics classroom activities as well, taking into account that several teams have to work together in the same room/place. We have developed an educational escape game for physics of fluids, as this topic is left out from the Romanian high-school curriculum. We have tried out our game during the project week called "Şcoala altfel" ("school in a different way") and in a physics camp for gifted students. We present the designed physics escape game and the results.

INTRODUCTION

Escape Rooms in General

Starting from Japan, the USA and different parts of Europe, the so-called "escape rooms" have flourished in the last decade. This is an adventure game used mainly for team building activities. Players work together in a team of 4 to 6 members, they solve puzzles using hints, clues and a strategy in order to escape from a locked room. To escape from the room, players should usually open several 4-digit coded locks. For that, players have to solve different puzzles to find out the code. They need to accomplish the task in a given period of time, usually less than one hour. The puzzles usually are: decrypting messages, finding information in a text, reading a text in a mirror, revealing invisible messages by UV-light, searching for items in odd places, combining parts together or triggering a magnetic lock [1]. A very detailed list of worldwide spread escape rooms can be found on escaperoomdirectory.com.

Educational Escape Rooms and Games

As we can see, the puzzles in an escape room, in many cases, use different physical phenomena, hence comes the idea of using escape rooms in science centers or even in classroom activities. The idea is very new: LabEscape, a quantum physics themed escape room opened its doors on January 28 this year (2017), under the tuition of the Physics Department from the University of Illinois [2].

The basic idea of gamification of the educational process is not new. Role-playing in a language-course is its most simple manifestation. Gamification could mean more than that, such as a game with avatars, levels and badges in a computer-environment. Here we use the word gamification in the sense in which Kapp defines it: "using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems" [3]. The advantages of gamification of the educational process were deeply studied by Nicholson [4] and why it works is easy to understand on the basis of the flow-theory developed by Csikszentmihalyi [5].

Escape rooms are designed for one single team of players, thus as an educational method it is more suitable for activities in a science centre, but with modifications it can be used in classroom activities as well (as escape games).

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Educational escape games have been tested in the last couple of years for several learning topics, and one can even purchase them from the internet (ex. Breakout EDU), or one can get useful hints for designing a new activity (for example on the site https://www.classcraft.com/blog/features/escape-room-education/). There are only few such activities developed for physics, mainly for middle-school students. These are related to heat transfer, atoms and eclipses (www.theescapeclassroom.com). We found no activities aiming at high school students.

We presume that with the help of educational escape rooms students are more likely to retain knowledge, as they can use what they have learned in a game, thus the students being involved in "active learning" processes.

EDUCATIONAL ESCAPE GAME ON PHYSICS OF FLUIDS

We have developed an educational escape game for the physics of fluids, as this topic is left out from the Romanian high school curriculum. Taking into account that in a class we have to form 4 to 6 groups of students and in educational circumstances we do not have the possibility to assure separate rooms for them, the groups will play the game in the same classroom. We designed the game to be a "break in" one (not a breakout one, as it is an escape room). It means that instead a locked door, there is a multiple locked box, where the teams have to break in (by finding the right codes of the locks), to reach the final goal of the game.

We have used our game during the project week called "Școala altfel" (school in a different way) at Apáczai Csere János High School in Cluj-Napoca with a group of 36 students from grades 9 and 11, and in a slightly modified version in a physics camp for gifted high school students selected from different schools from Transylvania, mainly from grades 10 and 11. Both activities took around 90 minutes plus discussions. For the design we have chosen the cheapest way: the codes (correct and incorrect codes, too) were written on envelopes, which contained new puzzles to solve. At the start, they got a page with the general instructions of the game and the first puzzle as well. They also got the full experimental setup for all challenges and a set of envelopes with different codes. In order to have a challenge they got two extra sets of envelopes with wrong codes and fake challenges or with letter bombs. Only the final puzzle led to a locked object. In the first case, this was a box with the setup for the Torricelli experiment with water, and we have made the demonstrational experiment together from the second floor of the school building. In the summer camp for gifted students the final codes of the four teams opened the locks, which blocked the garden swing, the main free time attraction of the participants.

Styx, the River

Every escape room has a theme. The setting should make the player feel as if they are transported with a time machine in a different place and time, somewhere in a place full of mystery. Styx, the river – is the name of our physics escape game, which suggests that it is about water and must be something mysterious. The game begins with a story and a mysterious picture:

"Your main task is to pass through the water of the Styx, the frontier dividing the realm of the living and the dead, which runs nine corners to the bottom of the underworld, where the palace of Hades is rising. To get to this river, you will have to pass through four other underworld streams: Lethe, Acheron, Cocytus and Phlegethon, which cross the hell and join in a huge, terrible swamp. You have to find a code in each task and you can travel from one river to the other by breaking the envelope marked with the appropriate code. On the banks of the rivers, there are envelopes with wrong codes, too. You are wasting your precious time by opening those envelopes!

Good luck, beware of getting lost! During your journey, you can ask the emperor's servants for guidance."

Thus, the students are put in the role of travelers in this mysterious world, and by this they are involved in a gamified active learning process. In the following, we will present the puzzles of the game.

First Puzzle: Lethe, the River of Forgetfulness

The students will find a puzzle entitled "Forgotten scientists", which presents an ordered set of 4 portraits of great scientists who did research in the field of fluid physics. They have to remember great scientists in order to take over the river of forgetfulness by solving anagrams that hide the full names of the scientists, and then put the numbers associated with the anagrams in the same order as the portraits. So they get a 4-digit code. For English, German, French or Hungarian language one can use an anagram generator: http://szotar.sztaki.hu/lab/anagram. Thus an English version of our first puzzle is presented in Table 1. When applied in the camp with talented students, we

used one more portrait and anagram: “blonde nose sorry” for Osborne Reynolds, coded 0, thus the final code was a five-digit one.

TABLE 1. English version of anagrams for the first puzzle.

Anagram	Code	Solution
Hermes used Africa cosy	6	Archimedes of Syracuse
retell ASCII Latin grove	7	Evangelista Torricelli
clap bias seal	8	Blaise Pascal
blue lanolin ride	9	Daniel Bernoulli

Second Puzzle: Phlegethon River, a Stream of Fire

For this puzzle each team had three different sized glasses: with diameters between 25 to 70 mm’s. The task for the students was to fill the glasses with water (“from the hot Phlegethon river”) all the way to the brim. After that, “in order to cool it down”, they had to pour in cold water with the help of a 1 mL syringe until it flowed over. This way they measured the total amount of water, which they could pour on the surface, seeing that it went over the brim of the glass, creating a convex surface. As a result, they learned about surface tension. By their measurements they could get the code according to the rule shown in Table 2. As there were three glasses, they had to use only three codes, which made the three-digit code number.

TABLE 2. Encoding the results of measurement in the second puzzle.

Measured volumes (ml)	Code
3–5	9
6–7	4
8–9	2
10–12	0
13–14	3
15–18	7

Third Puzzle: Cocytus, the River of Yawning

This puzzle is based on a simple Torricelli-experiment. Figure 1 shows the content of the envelope, which contains the instructions. For the gifted students we applied a modified version: they had to make a graph of the horizontal distance between the base of the jet of water and the bottle in function of the height of the punched orifice. In this case at least five orifices were needed. Millimeter paper was also provided. Students will also find a printed table with numbered letters of the alphabet, so they can find the right code to pass further.

Fourth Puzzle: Acheron, the River of Sadness

At the river of sadness (in the coded envelope) there is an easy, but surprising physics experiment. We have tried two different experiments: one with an average class and one with the gifted students.

In the first case, they got a glass, matches and a balloon. Their task was to lift the glass using only the given object, without touching the glass. The majority of the teams got the solution after only a few seconds: one of the students inflated the balloon, and others, with the help of the matches, heated up the air from the glass. The inflated balloon was placed over the glass such that it covers the entire mouth of the glass and no air escapes the system. If the team succeeded, they got a message hidden under de glass: “You managed to have a smile on Acherons face”. The code for this puzzle came out from the surface of the balloon, where we had previously drawn some pictures and numbers. Those could be seen only when the balloon was inflated.

With the group of gifted students we made a different experiment. The teams had to check the density of some fruits and vegetables and pick those, which were (in average) less dense than water, and put them in alphabetical order. We have also prepared a labeled balloon, which can be blown up (again to “bring smile on Acheron’s face”) and get the numbers associated with the fruits and vegetables. These provided the code. In our setup the following

were less dense than water: apple, cucumber, lemon and nutmeat. As more dense ones we used potato, almond and pealed orange.

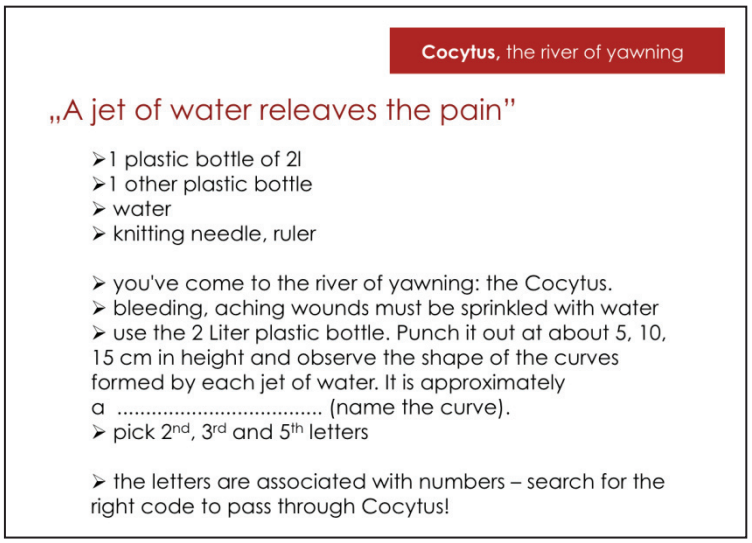

FIGURE 1. Instructions for the third puzzle

Fifth Puzzle: Styx, the River of Miraculous Powers

By solving the first four puzzles, the teams had reached the Styx River. In order to cross it they had to use a metal wire regular tetrahedron and immerse it in water. As we had previously mixed fluid soap with water, a soap membrane has been formed on the tetrahedron, as in Fig. 2. We have asked them to observe how many plane surfaces the formed soap membrane has in total. It turned out to be a surprising experiment for each group, as everyone expected to see membranes on the sidewalls of the tetrahedron, that is 4 surfaces instead of 6. By this experiment they have learned that due to the surface tension, the soap film will always be of minimum surface.

Finally, every team has got number 6 as the result, but they had to unlock different digital locks, so each team had to do one more calculus given on his last instruction-sheet to obtain their own three-digit code which opens one of the locks.

FIGURE 2. Soap membrane formed on a metal wire regular tetrahedron

Methodological Analysis

At the end of the game, we have discussed their experiences and the scientific background of the different puzzles. In the case of the scientists, we have specified the corresponding fluid physics research domains.

In case of the water membrane observed in the second puzzle, we have discussed that water has a high surface tension compared to other fluids, playing a very important role in different biological phenomena: like the movement of water strider on the surface of water ponds.

About the Torricelli's spill experiment we have discussed the findings of the Italian scientist during his research. He found the relation between the speed of the water jet flowing out of an orifice and the height of fluid above the opening. Only in the case of the gifted students we had time and found it appropriate to discuss in detail the mathematical background of the phenomena. The speed of efflux, v is the same with the speed of a body (in this case a drop of water) would acquire in falling freely from the same height, thus:

$$v = \sqrt{2g(H-h)} \tag{1}$$

where H is the height of water level in the bottle, h the height of the orifice from the bottom of the bottle. In our experiment if we consider the movement of the water jet as a horizontal projection we can find the D, the distance from the bottle to the place where the water jet meets the surface of the table:

$$D = 2\sqrt{h(H-h)} \tag{2}$$

which gives a parabolic curve D against h.

In the fourth puzzle we have tried two different experiments as presented above.

The project week gave us the occasion to clarify that by closing the mouth of the glass with the inflated balloon, after a few seconds (as air cools down) the balloon will be sucked inside the glass, as volume decreases according to the law of isobaric process. In fact, the friction forces between the balloon and the glass will stand against the weight of the glass when lifting the glass.

In the camp for gifted students, we have chosen the other experiment, as we were sure that they knew the other one, but to make experiments with different fruits might have been interesting even for these students. In our discussions, we laid a special emphasis on discussing the average density as they could see that peeled fruits have different density compared to the ones with the peel on them.

The last experiment proved to be a surprising one for the majority of students. We had to discuss that the formation of the soap membrane surfaces is due to the fact that energetically the minimal surface that spans the wire boundary is the most favorable.

We have asked the students to give feedback to the activities.

In the case of the average class, we had the opportunity to use internet connection, so we have prepared a quiz with a mobile application (create.kahoot.it). The quiz was completed after one week the activity was performed. Everybody enjoyed being part of this activity, and we could say that in a short period of time, they got some basic knowledge of fluid physics. The questions were the following: Q1. Which experiment surprised you the most?; Q2. Which experiment demonstrates the surface tension?; Q3. Which experiment demonstrates the atmospheric pressure?; Q4. Which experiment is connected with isobaric processes?; Q5. Who has studied the dependence of surface tension with temperature?; Q6. What is the reason of the round shape of soap bubbles?

At the camp for gifted students we made the feedback in written form, as we did not have any internet connection, and it was taken on the same day with the game. As the puzzles were slightly different in this case, some questions have been modified: Q3'. What is the connection in Torricelli's experiment between the height of the water column and the speed of the water jet?; Q4'. What would you do to the peeled orange to make it float on the water?

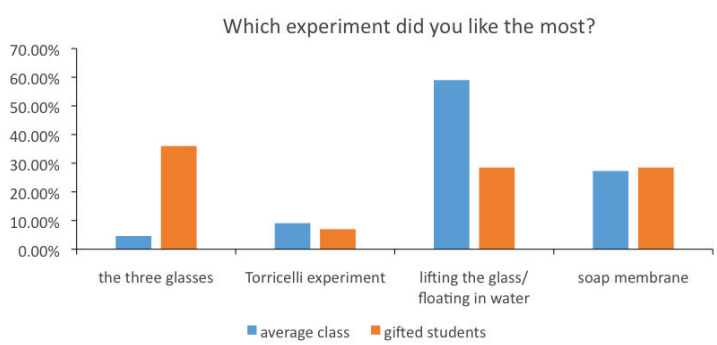

FIGURE 3. Percentage of students who liked the most the indicated experiment

According to the results from the first question each experiment surprised some students in both cases (see Fig. 3). As expected, the most surprising experiments done in the camp were those related to surface tension, as this is a

phenomenon totally neglected by the curriculum. The students from the average class liked the experiment with the lifting of the glass with the help of the balloon the most, as it needed creativity.

In case of the average class we got replies from 24 students, the evaluation is seen on Fig. 4, where we can state that they got problems only with questions related to surface tension, which could be explained by the lack of previous knowledge in this field. Question 5 was a tricky one, as it was a piece of information given in the statement of the second puzzle. Out of the 11 students with poor grades in physics, more than 50%, that is 6, gave at least 3 correct answers, which was surprisingly good.

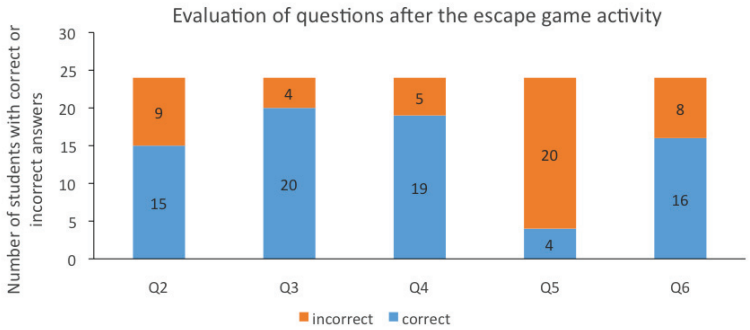

FIGURE 4. Evaluation of answers from the average class students

The school conducted a student satisfaction survey after the "school in a different way" week, inquiring 25% of the students of the school. The escape game was in the top ten most mentioned ones among the more than 50 activities of the week.

CONCLUSIONS

Gamification of educational process has multiple benefits: it is engaging (involves students' active learning), stimulates curiosity, gives the "flow" experience, and gives real learning tasks. From the evaluation we can conclude that students liked very much this kind of activity, they found it useful to get knowledge in a new field this way. Even students with poor grades in physics had good results in the final quiz. Many students stated after the activity that they had never thought how many things one could learn through a game like this. Students were pragmatic in their learning, retaining only the information that helped them solve the puzzles. The method is suitable for phenomenological study of a new phenomenon, but to provide a deeper understanding, extra classes are required.

Preparing an educational escape game is very time consuming, but the setup could be used several times with subsequent groups of students.

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