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Editors • Mihai Lungu, Alexandra Popescu and Ciprian Sporea

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Fluid Dynamics Knowledge Comparison of Students with Different Educational Background

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Abstract. Escape games are useful in the informal teaching of physics or outreach programs, and in the last few years we studied its efficiency as a tool in physics teaching [1]. We designed an inquiry-based learning project on fluid mechanics, a topic missing both from the Hungarian and Romanian physics curricula. The goal of our study was to compare previous knowledge on fluid mechanics of student's coming from different educational background. Activities were conducted with three similar groups of students in two high schools from each country. More specifically, we worked out a classroom escape game on fluid dynamics, where participants had to use several informational sources. We combined history of science topics, the use of the internet (both for getting information from and gaining motivation), and "in-situ" experiments. The tasks covered basic concepts, application of hydrodynamic pressure, and the study of von Kármán vortex street. We have tested this learning project with students of different interest, different educational background and of different age (year 9 and 11). We made a research on differences in the intrinsic physics knowledge of students from the two countries using the tools of methodological research: semi-structured interviews and surveys (also postponed tests by a quiz to see the long-term results). We found some similarities and some differences in student's knowledge from the two countries. Our inquiry-based learning project helped students to gain phenomenological scientific literacy in a cooperative way.

ESCAPE GAMES AS AN EDUCATIONAL METHOD

Recent research [2] show that different informational channels in classroom activities allow sharing creative solutions with peers, for instance, by mobile phones through photos and videos. STEAM pedagogy, which integrates art in STEM [3] is a promising alternative.

Escape rooms developed as a leisure activity in the last decade. They are adventure games suitable for team building. 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 open usually several 4-digit coded locks. There is a time limit to escape the room, usually 45-60 minutes. Universities and Science Centers first recognized the utility of escape rooms for educational proposes. LabEscape, a quantum physics themed escape room opened its doors in 2017, under the tuition of the Physics Department from the University of Illinois [4]. A general science related escape room was designed by Mobilis Interactive Science Center in Győr, Hungary (http://mobilis-gyor.hu/mini-paniq-szoba). The escape rooms were used not only for science topics, but also for literary topics, such as the 2016 themed game for the Genesee Valley School Library Network in New York [5].

Another area of application are escape rooms designed specifically for the educational (university or school) environment, that is, for the simultaneous work of several groups in the same space. For the fourth year, such an educational package is offered by breakoutedu (https://www.breakoutedu.com/) and theescapeclassroom (https://www.theescapeclassroom.com). For university education, there have also been successful attempts of escape room activities: used for informatics [6], for chemistry [7], and pharmacology [8]. Similarly, for high school students,

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the CERN Research Center's Department of Teacher and Student Programs developed a particle physics game for students in a summer camp [9].

DESIGN OF A NEW ESCAPE GAME FOR PHYSICS OF FLUIDS

Our goal was to implement escape rooms in a classroom environment. A game was first developed for fluid physics in the spring of 2017, presented in detail in previous publication [1]. This first activity was a real novelty for the students, and as part of the 2018 *School in a different way* project week, 35 of our 176 surveyed students requested that we re-arrange a physics escape room. That is, more people than the previous year could attend. In response to this request, we designed a new game, which again focused on the physics of fluids, with a whole new set of tasks. Compared to the previous year's activity, we made the following innovations: a padlock and a coded seven-digit safe was purchased. With the padlocks, we closed backpacks and pen cases that contained the subsequent worksheet. We also used a wall-mounted laptop case in the physics lab, which was lockable with a key. In this box, we hid the key to the lab entrance door. In this way a real escape room environment was produced. The sequence of tasks had a linear structure, and the time frame was 50 minutes, in order to include in one classroom activity. At the beginning of the activity, the teams were given a frame story and the experimental tools. It was a novelty that the first task sheet had to be found hidden in the lab by all teams, as well as the coding sheet shown in Figure 1.

A	B	C	D	E	F	G	H	I
1	2	3	4	5	6	7	8	9
J	K	L	M	N	O	P	Q	R
10	11	12	13	14	15	16	17	18
S	T	U	V	W	X	Y	Z	
19	20	21	22	23	24	25	26	

FIGURE 1. Coding of the letters from the alphabet with numbers

The first task was a crossword puzzle: *Who was Daniel?* This helps students to learn about the implications of the Bernoulli's Principle through two experiments. One is to move the coin on the table top to the plate next to it without touching the coin (Figure 2). They could do this by blowing over the coin parallel to the table top. Another experiment was to blow between two sheets of parallel paper. The completion of the two experiments and explanation of the observed phenomena was required to solve the crossword puzzle. Students could obtain the code by matching the letters in the highlighted boxes of the crossword puzzle with numbers using the coding sheet (Figure 1).

FIGURE 2. Simple experiments for showing consequences of Bernoulli's Principle

The students did not know the applications of Bernoulli's law, and in many cases needed help to have a sense of success. In the case of coins, of course, the students first tried to blow under the coins, so had no success in lifting them in to the plate. In the case of sheets of paper, there was also a team that had trouble interpreting the parallel

positioning of sheets of paper, so they were placed side by side and tried to blow between sheets. However, the crossword puzzle was completed in most cases after a successful attempt. In some cases, students sooner realized the answer to the question (highlighted in the crossword) and no longer filled in the horizontal lines. The solution of the crosswords was Bernoulli.

FIGURE 3. The Cartesius diver experiment with a bottle and test tube.

In the second task, they made the experiment with a Cartesius diver in a half-liter plastic bottle with a test tube (Figure 3). While studying this experiment, in order to work out the diver's operating principle, the team had to fill in the following incomplete text: "If the volume of the bottle decreases with compression, the air pressure inside it .....1... .., due to that the water level is ..... 2 ..... in the test tube. Thus, the tube average ..... 3 ..... increases. As a result, the diver is ..... 4 ..... After this, if the .....5 ..... exerted on the bottle is reduced, then the diver is ..... 6 ..... With the right size of .....7 ..... the diver can even ..... 8 ..... in the water. The missing words had to be written in the following order: increases (1), rising (2), density (3), falling (4), force (5), rising (6), thrust (7), floating (8). The following code was given by the birth date of René Descartes, so the value of the four-digit code is 1596.

The majority of students did not new the Cartesius diver experiment before, and many found it difficult to see how the test tube could move up and down. After a successful experiment, more than 75% of students completed correctly the first six missing words in the above sentences. However, only very few (18%) realized that the last missing word was the phenomena of floating.

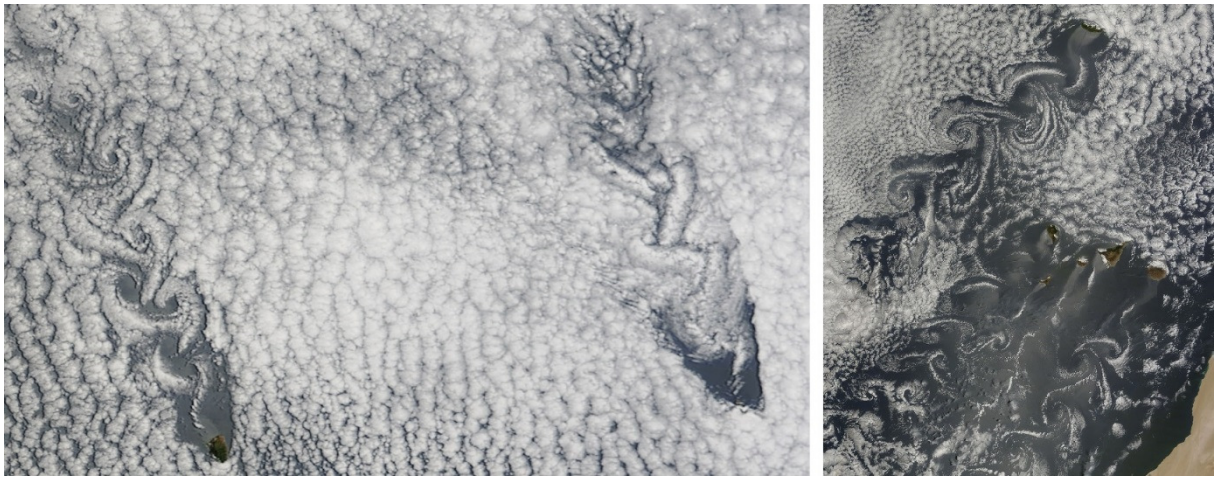

FIGURE 4. Wortex streets above Alejandro Selkirk and Robinson Crusoe islands (left, source of the image: *https://earthobservatory.nasa.gov/images/80197/von-karman-vortices-off-chile* and the Canary Islands (right, source of the image: *https://eoimages.gsfc.nasa.gov/images/imagerecords/85000/85989/canaryIslands_tmo_ 2015140_lrg.jpg*.

In the third and final task, teams were able to analyze the Kármán vortex street based on NASA's recordings over the Pacific and Canary Islands. In these cases the vortex occurs due to the mountains on the surface of the islands, which stand as an obstacle to the moving clouds (the airflow). For the vortex streets, they had to examine two aerial photographs (Figure 4) where the distance between the islands could be measured using the googlemaps application. This way the students could estimate the total length of the vortex and the distance between two successive vortexes. This allowed them to realize the magnitude of this phenomenon, which reaches hundreds of kilometers. A third image is a laboratory-generated Karman vortex series at the University of Chicago (Figure 5). A 2.5 cm high barrier ("tip") is placed at the bottom of the vessel, marked with a red arrow in the picture. The water depth is approximately 7.5 cm. As the vessel rotates, the water inside it rotates relative to the vessel. The students had to determine the size of the vortex line in the cylindrical vessel, knowing the diameter of the vessel, which was 35 cm. From these measurements, students could see that the Karman vortex series can be formed in different media (air and water) and in very different sizes (from a few cm to a few hundred kilometers).

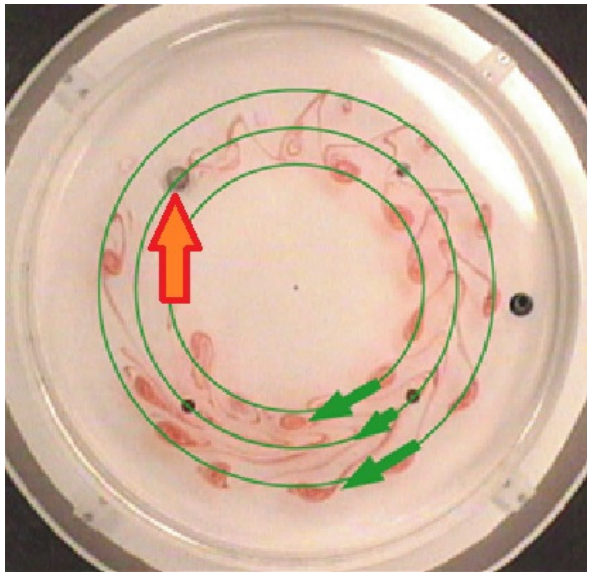

FIGURE 5. Water vortexes in laboratory conditions, induced in a vessel on a rotating disk, where the obstacle is placed at the bottom of the vessel, indicated by the vertical arrow.

EVALUATION OF THE ESCAPE ROOM ACTIVITY

The escape game method was tested on a larger sample group for students of different educational background and age. Activities were conducted with three similar groups of students in two high schools from Hungary and Romania respectively as shown in Table 1.

TABLE 1. Key data's of the six participant student groups at the escape room activity

Name of the school	Profile of the class (abbreviation)	Number of participants	Number of groups	Successful groups	Participants in the test
Madách Imre High School, Budapest, Hungary	9th grade humanisctic class (9M)	28	6	1	24
	11th grade humanistic class (11Mh)	25	6	5	22
	11th grade science class (11Mr)	21	5	5	13
Cluj-Napoca, Romania Apáczai Csere János Elméleti Líceum	9th grade humanistic class (9A)	27	6	5	27
	11th grade humanistic class (11Ah)	28	6	5	27
	11th grade mathematics-informatics class (11Ar)	24	5	5	21

The fluid dynamics escape game initially was aimed for students from 11th grade of science or mathematics-informatics classes. Later with this survey we wanted to see if the activity could be used for students of younger age groups (in our case 9th grade) or for those studying in humanistic classes as well. Additional aim was to explore the differences that may exist between the knowledge of students from Hungary and Romania. As seen above the same escape room activity was conducted subsequently with three different student groups from two high schools from the two countries. Successful teams were considered those who could finish all the task in order to escape the room, in the given time limit of 45 minutes.

The table also shows that 26 (75%) of the 34 teams succeeded. In fact, only for groups from one class, the time limit was too tight, which was probably due to my fault, as it was my first group at Madách Grammar School, and I didn't know enough about the room where the activity took place.

The escape room activities were conducted in both institutions in the second semester of the 2018-2019 academic year under the same conditions. For each class, we completed a test a few weeks after the activity, with questions related to the knowledge acquired during the escape game. Unfortunately, as shown in Table 1, the test was completed less than the number of participants in the activity. The test was designed with the help of the *quizizz* mobile application (www.quizizz.com). The 13 questions were given 4 answers each, of which one was the correct answer with one exception, where we had three correct answers. The results are separated into two categories, according to the scientific way of thinking and the memorization of information. The first category contains questions that provided a scientific explanation of the experiments performed during the task, while the second category mainly asked for biographical information from scientists related to the topic, and discussed in the activity.

TABLE 2. Difficulty index (P) of the test questions per classes for scientific thinking.

Question number	Abbreviation of classes according to Table 1.					
	9A	**9M**	**11Ah**	**11Mh**	**11Ar**	**11Mr**
1	0.52	0.50	0.48	0.55	0.71	0.92
2	0.44	0.42	0.52	0.59	0.57	0.54
3	0.70	0.58	0.37	0.45	0.57	0.77
4	0.56	0.45	0.56	0.50	0.76	0.92
5	0.56	0.50	0.52	0.59	0.71	0.69
8	0.56	0.58	0.63	0.45	0.86	0.85
11	0.63	0.62	0.70	0.68	0.95	0.90
12	0.44	0.62	0.52	0.64	0.90	0.95
Mean value	**0.55**	**0.53**	**0.54**	**0.56**	**0.75**	**0.82**

The P difficulty index in Table 2 and 3 expresses the percentage of students in the group who answered to the question correctly. It can be seen from Table 2 that, practically regardless of class, the questions asked were of medium ($P \in (0.5; 0.7)$) or mild ($P > 0.7$) difficulty [10]. There is no significant difference between students of the two schools and students of the same interest and grades. Interestingly, the performance of 11th grade students with a human interest is very similar to that of their peers two years younger. It may be said that, in the absence of interest in science and physics in particular, they do not show progress in scientific thinking. I found significantly better results in case of 11th grade science class students in both institutions. This was already evident during the activities, as the tasks were solved much earlier, more accurately and with the correct use of scientific language. This was, of course, to be expected of them.

In the case of information memorization questions (Table 3), similar conclusions can be drawn as for the scientific way of thinking, with the difference that results are 5-20% better in this case.

It is also worth analysing the students' views on the escape game activity itself. They had the opportunity to express themselves unstructured, expressing the positives and negatives of the activity in a few sentences. On the positive side, they described the following:

- we had the opportunity to freely ferret about in the physics lab (the first activity sheet was hidden behind the wall cover, in the tool cabinets, etc.),
- it was exciting to open a safe for the first time,
- students views were not driven entirely by a teacher-driven line of thought,
- without the use of the internet, one could not escape from the physics lab,
- the astonishing result of the Cartesius diving experiment,
- explaining physical phenomena in crossword puzzles,
- the teacher as moderator of the activity was helpful and kind.

TABLE 3. Difficulty index (P) of the test questions per classes for memorizing information.

Question number	Abbreviation of classes according to Table 1.					
	9A	**9M**	**11Ah**	**11Mh**	**11Ar**	**11Mr**
6	0.93	0.63	0.78	0.50	0.86	0.54
7	0.63	0.46	0.59	0.45	0.86	0.85
9	0.52	0.50	0.56	0.82	1.00	0.77
10	0.70	0.77	0.78	0.77	0.95	0.92
13	0.52	0.58	0.67	0.59	1.00	1.00
Mean value	**0.66**	**0.59**	**0.68**	**0.63**	**0.93**	**0.82**

Negative student opinions:

- time constraint, time was too short,
- in some cases the relationship between task and code was very loose (for example, in Cartesius diver),
- many teams concentrated in small spaces.

Of course, time has emerged as a stress factor that is not able to motivate everyone, so the method cannot be applied to any group composition. It is important that there are at least 2 students in the group who can motivate the others, assign tasks to them, and thus make teamwork effective. The lab, which is quite spacious in a normal classwork activity, proved to be tight in this situation. The students had to move around the room, look for the worksheet, padlocks, safe, and it would have been good if there had been a greater distance between the teams so that they would not interfere with each other's work.

CONCLUSIONS

The use of escape games in education is not unique, but it has only begun to spread in the last 2-3 years. However, this fluid dynamics escape game can be considered to be a pioneer for in the classroom secondary school physics activity. The subject of fluid mechanics, as an extra-curricular area, makes it extremely interesting for students.

Based on the survey presented above we can conclude that students have a basic knowledge of fluid mechanics that they could use to perform the experiments. They found the topic interesting and deserving of further study. Based on the survey results, it can be said that the efficiency of learning is high in research-based teaching methods. Escape room activities may be one of these strategies. The activity was suitable to introduce a new phenomenon, to discuss phenomenological, but more time is needed for a deeper understanding, which, unfortunately, is currently not allocated in the curriculum timeline.

Escape room activities can develop skills such as complex problem-solving and communication (social) skills, which the World Economic Forum's 2016 report identifies as crucial for future employees [11].

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