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A Virus Infected Your Laptop. Let's Play an Escape Game

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Abstract: Have you ever thought what would happen if a ransomware infected your laptop? This type of virus kidnaps files and encrypts them, and the only way to recover the data is by paying in bitcoin or some other cryptocurrency. This situation is undoubtedly terrible. All of your work, projects, and personal files will not be available (unless you pay the ransom). The first time students watched a video that contextualizes this stressful situation, they thought that they had been attacked by a computer virus. Fortunately, the panic only lasted a few seconds. This is the way to start a game called breakout or escape room. The difference between these two words is that, in the first case, the goal is to open a padlocked box, while the objective of an escape room is to find the key that allows to get out of a room. Both games are similar, containing riddles, puzzles, problems and some clues that would help the players to find the solution. This study analyses the use of a breakout game for educational purposes, more specifically in a university context. The experiment conducted mixes game–based learning methodologies with engineering students learning Linear Algebra, Calculus or Cryptography, which has allowed us to obtain promising results about the usage of this methodology.

Keywords: breakout; escape room; game-based learning; engineering education

1. Introduction

Many educators are concerned about how to motivate engineering and applied science students concerning mathematics lessons. As those students have a different profile than students of the Mathematics degree, teachers try to find a way to engage first and second-year undergraduate students in learning math topics and get them more involved in classes. It is not common to use games for learning Linear Algebra, Calculus, Numerical Methods, Mechanics, Thermotechnics, or any other undergraduate degree subject, although these courses are included in the first year curriculum. The difference between secondary or high school and the university is very high, and many students underperform due to this reason.

At the university level, students are expected to learn theorems and demonstrations, solving problems in a "classical" way. The use of games is not widespread in the university context, and some experts deem

them to be unfitting for university teaching. Despite this, the use of games in undergraduate engineering education is increasing [1].

In recent years, escape games have experienced a significant boost. The number of results when searching in Google Academics using the words escape, room, classroom, higher, and education gives an indication of the level of interest of these activities (initially designed as leisure activities) in university contexts. Moreover, in a study developed for analyzing serious games in health education, authors found a growth in the number of publications about this topic [2]. This increase is also reflected in an online survey from The Codex (https://thecodex.ca/), a group of escape game enthusiasts, who observed that the number of people interested in this topic had doubled in 2018 [3]. This could be considered a clear indication of the many projects and experiences that are taking place in this field.

The educational potential of game–based learning (GBL) in medical education has been demonstrated in [4,5]. Multiple-choice tests, fill-in-the blanks-based problems together with a traditional escape room could help to learn about symptoms of critical limb ischemia, basic vascular surgery, technical skills such as embolectomy or ultrasonic imaging, or cardiovascular medications in a pharmacology course [6]. In this proposal, Hermans et al. used an escape game in a pharmacology course for nursing students, specifically to facilitate learning about cardiovascular medications. For educators, the main objective was to develop a meaningful learning experience. After carrying out the activity, 74.8% of the 119 students that participated thought it was a valuable experience and appreciated the opportunity to work with their peers. However, the results also show the level of frustration of students during the game for various reasons, mainly the lack of time to solve the puzzles and riddles.

Caraballo-Martín et al. [7] used games as a tool for teachers assessment and self–evaluation for students of the Degree in Economic Analysis. In this experience, professors teaching different subjects (such as mathematics for Economic Analysis I and II and statistics for Economic Analysis II) participated. In addition to making students aware of what they had learned in subjects with quantitative content, this experience intended to promote collaboration, teamwork, specialization, and adaptability of students. These competencies are considered desirable skills demanded in the business world [8,9].

In the case of computer science, subjects such as programming [10,11]), computer networks [12] or cryptography [13] contain problems and activities similar to the puzzles and riddles of an escape game.

The game–based learning methodology has also been used with students of the master degree in teaching of compulsory secondary education and high school, as part of their training as future teachers [14].

In secondary education, there are many interesting experiences. For example, Vita & Sárközi [15] developed an educational escape game for the physics of fluids, as this topic is not included in the Romanian high–school curriculum. These authors conclude that gamification in teaching environments has multiple benefits: it motivates students, encourages active learning, stimulates curiosity, and provides them with "real" learning tasks. Students enjoy this type of activities, as they find it useful to acquire knowledge in a different way. Even students with the worse grades in physics obtained good results in the final test.

Another interesting activity was carried out by Peleg et al. [16]. They designed all the material for an escape room for high school chemistry students that has been used by more than 350 teachers in Israel with approximately 1500 students in different phases. The results show that students were very motivated with this activity and appreciated the efforts of teachers to implement it, which increased the effectiveness of teamwork. As of today, it is still a helpful tool to promote chemistry in high schools.

Clarke et al. [17] presented a pilot study that was used to assess the feasibility and acceptance of university academic staff to incorporate interactive GBL in an environment of higher education. The educational objective for gamers was to develop skills such as communication, leadership and

teamwork throughout their experience. As conclusions, Clarke et al. [17] stated that they had found a high level of interest among university professors to include this type of experience in their teaching work.

During recent years, teachers have been preparing students for applying what they learn to real situations, while they try to solve engineering and scientific problems [18,19]. However, considering that mathematics subjects are usually part of the first and second-year courses, they do not have enough experience, since many real-life situations require a deeper knowledge about other engineering subjects [20]. In undergraduate engineering degrees, mathematics is a set of tools that students need to solve mechanical, automatic or electricity problems, but it is not an end in itself, it is only the instrument to solve engineering problems.

Two main contributions are presented in this paper. After an overview of the state of the art related to student motivation through educational breakouts (also known as Breakout Edu [6]) and escape rooms (EscapED [17]) at the university level, Section 3 provides the details of the breakout that was implemented by the authors of this contribution with different groups of students. The second part of this study is the analysis of the results obtained after playing the breakout game with students from different university courses. That information is included in Section 4. Finally, conclusions are presented in Section 5.

2. Engaging and Motivating Students with Escape Games

The most widely used method employed to teach is transmitting information and contents to learners (transmission model), but sometimes that is not the best way to engage students. Incorporating a student to a context that can be modified by the students' choices and actions is the best way to increase their engagement. It is generally accepted that members of Gen X, Gen Y, Gen Z, and millennials are more familiar with the pragmatics of playing games than grappling with theoretical concepts [21]. If the game is effective and achieves its goals, it must be aligned with the learning objectives. Game–based pedagogy is a potential tool for enhancing some specific skills in undergraduate students, such as written and oral communication [22].

An escape room is defined as a team–based game where players have to "escape" from a room filled with challenges within a given time limit. The players must solve the challenges located in the room, discover clues and objects scattered around, and use them for solving the puzzles, accomplishing tasks, and passing milestones before escaping from the room [23,24]. Riddles and puzzles are challenges that require using mental effort to solve problems logically [25]. Herman et al. [6] believe that this approach is consistent for young students who have grown up accustomed to virtual strategy games.

Flow is considered by Czikszentmihalyi as "the process of total involvement" [26], when individuals are fully engaged in a task that is the only goal at that moment. The idea of flow is always an important part of games, and therefore also in escape games, as the final goal is not only to play and win, but also to learn during the process. When a student is playing the breakout game, the first goal is to get involved on it, to be part of the discussions, and finally the desire to open the final padlock.

The situation with games could be somewhat compared to the situation of students solving a problem: if the problem or the game is difficult and they cannot find a way to solve it or identify clues for continuing, they get frustrated and give up [24]. On the other hand, when students are asked to solve routinary problems, they usually get bored. Thus, the content and the procedures of the game must be appropriate to the gamers' (students') level [11].

A movie, a book or a story creates an immersive experience. The spreading of a biological virus, fighting zombies, saving Earth from an alien invasion, or finding the key of an Egypt tomb are some examples of game contexts that set the atmosphere and lay the foundations of emotional investment and curiosity within the players [17]. Themes are designed according to a designer's creativity. In the end, the main goal is to involve the whole team playing the game.

The design of puzzles and riddles can take many forms: they can be linear with a unique path, where players have to solve sequentially several trials; multi-linear with several paths that make possible to work on different tasks at the same time; or it can be an open game where players have access to all puzzles and have lo link them before reaching the goal [27].

These characteristics make this game–based learning methodology a constructivist teaching method, as students learn by experimenting and "by doing". Teamwork, solving puzzles and problems, and finally, reaching the goal, can be designed with educational objectives. Moreover, as it is a competition, students are motivated to participate and to win. The use of breakouts or escape games develops creativity, critical thinking and creative learning in participants. Novelty, involvement and meaningfulness are the strategies that positively affect students interested in learning sciences [28]. When these stimuli are integrated into a class, students' previous negative interest in science contents is transformed into a positive one.

Students engagement in the learning process is a personal process, and the impact of playing a game depends on the players' individual differences (i.e., gaming proficiency, personality, preferences, and emotional state) [29]. The learning environment includes the game environment and also pedagogical aspects [30]. In educational contexts, riddles and puzzles are designed to cover competencies and contents of specific courses. Some escape rooms or breakouts are being used by university students, for example, for a third-year professional pharmacy management course [31,32], and also for residents from 1st to 4th academic year [33]. In this case, the escape game included clues and puzzles from physical exam findings, lab abnormalities, electrocardiograms and radiographic images.

Another fundamental aspect of this type of activities is teamwork. One of the keys to succeed is precisely that the students who participate in the game must coordinate their responsibilities properly, so the group achieves its goals. In this sense, Nicholson [23] concluded that the best teams are those formed by players with a wide variety of experiences, skills, previous knowledge, and physical abilities. Groups made by people who already knew each other are also more effective. The ideal number of individuals to form each team is four people [23,34].

When we watch original series on a streaming service without getting immersed in the episode, it is considered only as an entertaining activity. What is desirable in educational contexts is to obtain the involvement of students in classes and in all activities of the courses. In this sense, meaningful experiences are only revealed in face-to-face situations [35]. Moreover, the fun element of a team game makes it possible to learn contents and also acquire competencies in a more memorable way [36].

Personal involvement, meaningfully relevance and novelty are the qualities more highly identified by students that make the learning process enjoyable. Then, students perceive the instruction activity based on their personal interests and goals. On the other hand, the teacher-student relation affects the students' attitude towards the topic or activity based on the personal attention and encouragement they receive from their teacher [28].

The use of informal science education (visiting museums, zoos, botanical gardens or science museums where students can learn by interaction, or using games) is increasing in primary and secondary education [37]. There is a need for preparing science educators so they can guide students in non-educational contexts. Something similar is taken place in higher education, where the need of acquiring competencies is sometimes higher than learning contents.

3. Description of the Breakout

The escape game described in this contribution was designed for first-year undergraduate engineering students attending a Calculus course.

Some common aspects of this game are indeed part of most escape games. Thus, for example, the chronometer or an initial video are typically used in this kind of experiences.

3.1. History

Students participating in this game are familiar with computer viruses and the spreading of malware. As some of their teachers and trainers work together in the European project Rules_Math, we showed them the video located at https://www.youtube.com/watch?v=AxI0KC6fbew about a project meeting. Partners work in different EU countries and in different research areas, such as Computer Sciences, Electronics, Optimization, Information Security, Cryptography, etc. Suddenly, the laptop is invaded by a ransomware virus called Wannacry. Some students have heard about this cryptoworm, as the worldwide cyberattack that used that software took place in 2017. Now, our personal data is under imminent danger. A clue for the game is that gamers' identification is a key. After the video finishes, the game starts.

Figure 1 shows four different identification items in the game: Blue (square), red (triangle), green (pentagon), and yellow (hexagon). This information will be useful for players throughout the game.

Figure 1. Gamers' identification items.

Apart from the identification, students are given a road map and instructions for the game, so they know that they form part of a specific team (either blue, red, green or yellow). They also know from the road map (see Figure 2) that some riddles and puzzles must be solved by the team and some others by all the teams working together. The most important thing for the game is that teams are identified by a color, a figure and a number (given by the number of sides of the figure). This will help players to solve the puzzles and finally to win.

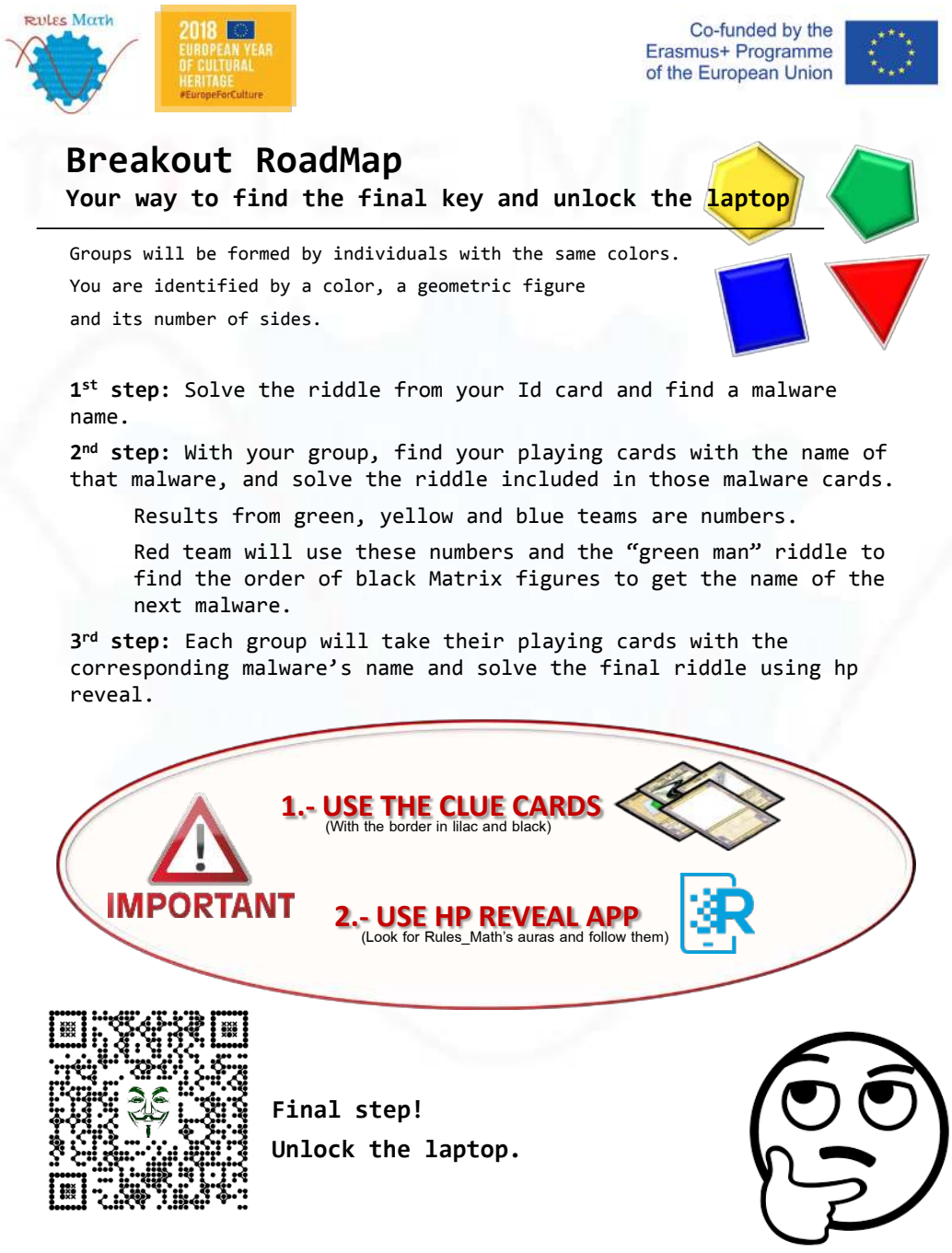

Figure 2. Road map with Breakout instructions and steps.

3.2. Material

When the game starts, there is some material available to all teams:

- Blue, red, green, and yellow Magic cards with different figures and text written on them. All of them with the name of different malware.
- Black and purple border Magic cards. These are clue cards to help gamers.
- A Domino game.

- Black Matrix figures: a square, a hexagon, and a pentagon with some 0's and 1's similar to the Matrix film.
- Some boarding cards like the one shown in Figure 3 belonging to Isaac Newton, Leonardo De Pisa, Albert Einstein, Evariste Galois, etc.
- Some other riddles and puzzles.
- The HP Reveal App will be needed during the breakout. This augmented reality application triggers overlays when the smartphone scans a selected image. Gamers are told that they will need this App and that they must follow the gamemaster's account (if they don't do it, it will not work).

Figure 3. Boarding card of Albert Einstein.

3.3. First Step: Riddle from Identification Cards

After solving the riddle from the identification cards, each team will obtain the same result: 13. These are the riddles:

- Blue riddle: September, 2019; November, 2015; June, 1969; August, 1999; October, 2000. What have these dates in common? (All those months have the same weekday for the 13th, which is Friday).
- Green riddle is to solve a system of linear equations and find the value of y: $2x + 5y - z = 14$; $-x - 3y + 2z = -6$; $4x - y - z = -110$.
- Yellow riddle is to solve a second-order equation: Find the x-coordinate where the parabola $-23 + x^2$ cuts the line $2x + 120$. Although the answer is double: -11 and 13, there is no malware's name related to -11.
- Red riddle: We are looking for information in these books: Algebra, page 85; Calculus, page 184; Statistics, page 229; Numerical methods, page 76. What do these pages have in common? (The sum of the digits of each page is the same: 13).

3.4. Second Step: Riddle from Friday 13th Cards

Once each team obtains number 13 from the Id QR code, they must take their corresponding card (Figure 4).

Figure 4. Magic cards with Friday 13th malware.

As part of their team (defined by colours) and using the Friday 13th playing cards, students must solve the riddle included in those malware cards. The road map sheet includes some additional information:

1. Results from green, yellow, and blue teams are numbers.
2. Red team will use these numbers and the "green man" riddle to find the order of black Matrix figures to get the name of the next malware.

Riddles included in Friday 13th cards are:

- Blue card image hides a domino piece. This team must play domino and find a number after some derivation and integration operations. The final number is 6.
- Green card image includes the U.S. National Security Agency logo. The real logo says "NATIONAL SECURITY AGENCY" and "UNITED STATES OF AMERICA", but the game's logo has changed the second sentence to "QR CODE - ALBERT EINSTEIN". Gamers must look for some other material related to Albert Einstein, i.e., the boarding card. The card QR code leads us to an Adobe Spark video where we can see a man (similar to Einstein) that says: "The number that you are looking for is number four".
- Yellow card contains the information: "magic card game" and something about this cards game: "You will lose if you lose all your cards". Among the materials that are available for all players, there is a riddle with the figure of a Magic card game in a table (see Figure 5). The answer to this riddle is 5.
- Red card: from the road map, players know that red team needs the numbers found by the rest of teams (6, 4, and 5), and the "green man" riddle to find the order of black Matrix figures (see Figure 6) to get the name of the next malware. This is a difficult riddle because gamers must pay attention to the green man and realise that green, yellow, and blue figures (in that order) are directed towards the city. This is the order of the Matrix geometric figures (the same as left figure): blue at the top (square, 4), yellow in the middle (hexagon, 6), and green at the bottom (pentagon, 5). After getting this, it is easy to convert binary numbers to decimal, and then get the corresponding letters: 19 (S)-20 (T)-21 (U)-24 (X)-14 (N)-5 (E)-20 (T).

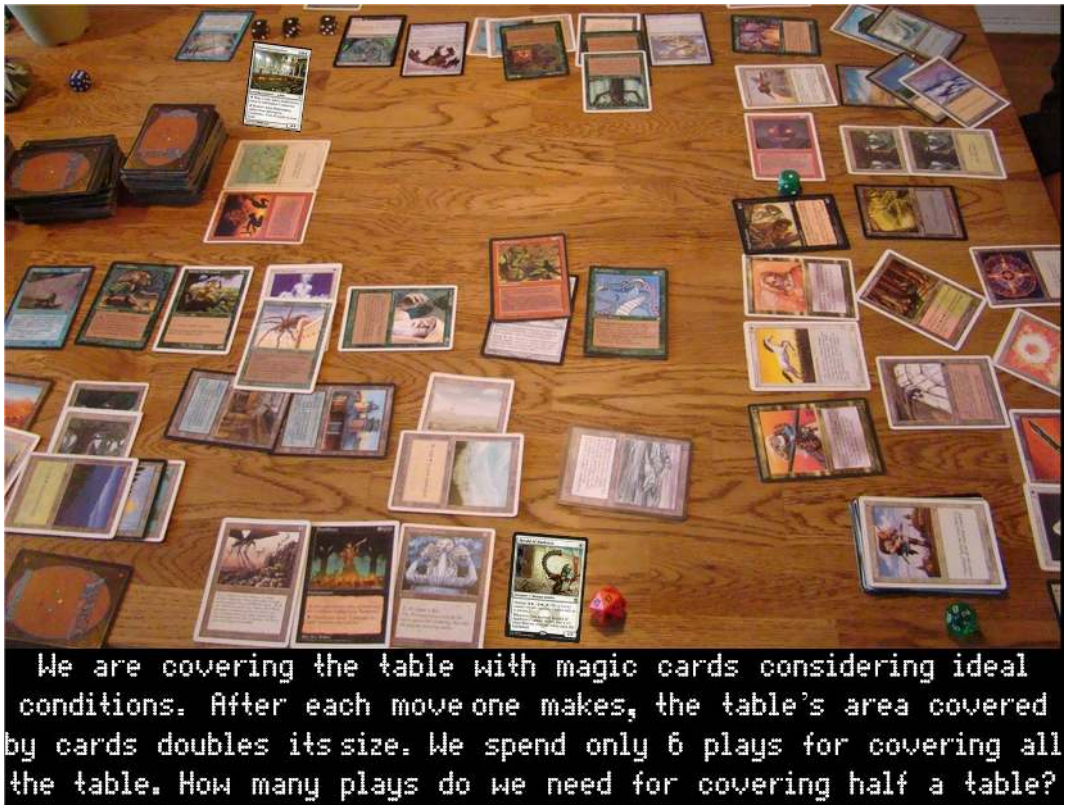

Figure 5. Magic cards' riddle.

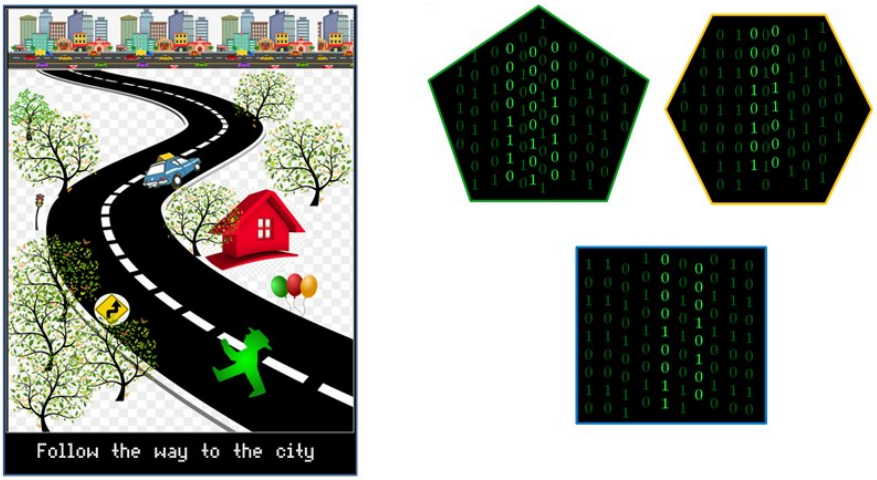

Figure 6. Green man riddle and Matrix figures.

3.5. Third Step: Riddle from Stuxnet Cards

By now, players have the name of Stuxnet virus and must search their cards to solve the final riddles. As it is mentioned in the road map, it is important to take into account that clue cards are also available and that gamers will need the HP Reveal App. The result of using this App over the Stuxnet cards is shown in Figure 7.

Figure 7. (**a**) Teams' Stuxnet cards; (**b**) Clue cards when using HP Reveal over (**a**); (**c**) Final result when using HP Reveal over (**b**).

At this stage in the breakout, the "big" problems that are detailed in what follows must be managed by the players.

3.5.1. Blue Stuxnet

The information obtained from the cards and the QR code is:

1. "Integrate what you find".
2. "The orientation must be taken into account".
3. "We have to cover this area with a piece of resistant material. Which is the area of the hole that we need to cover?".
4. "When we need to calculate the area of a surface, we use the definite integrals. Do you remember how to calculate integrals?".
5. The link to this video: https://youtu.be/9_fkoUHXrck.

Using the proper operations, the area associated to Figure 7b-1 is 10.

3.5.2. Green Stuxnet

The information available to the green team is the following:

1. "Pipeline system".

2. ”This system is similar to a traffic flow, where everything coming into must leave, i.e., everything that go inside has to go out”.
3. ”You must pose a solution using linear equations”.
4. A link to genial.ly that includes information about the pipeline system (https://bit.ly/2tanbjo).

The solution is the amount of microcontrollers that go out in corner D, which is 900.

3.5.3. Yellow Stuxnet

In this case, the information provided by cards is the following:

1. ”Earthquake and vibrations”.
2. A link to online information located at https://bit.ly/366PuOe.
3. A Mathematica file with the solution is also available as part of the materials.

The answer to this problem is the fundamental vibration mode, only the integer part, which is 0.

3.5.4. Red Stuxnet

For the red team, the information available is the following:

1. Law of cooling.
2. Newton’s law of cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature.
3. Online information at genial.ly platform. The link https://bit.ly/36bEgby includes some interactive elements such as the link to a Mathematica file, called breakout-Newton-CLUE.nb with the problem almost solved.

The result of this heating and cooling problem is 37°.

4. Discussion and Results

The whole breakout steps are detailed in Figure 8. Teams must play against other teams; however, in the second step, after finding the Friday 13th solution, all teams must work together. Blue, green and yellow teams must facilitate their solutions to the red team, which is responsible for finding the next virus name and sharing it with other teams. This step was confusing for students, as they expected to compete against the rest of the teams in order to win, not to collaborate with them.

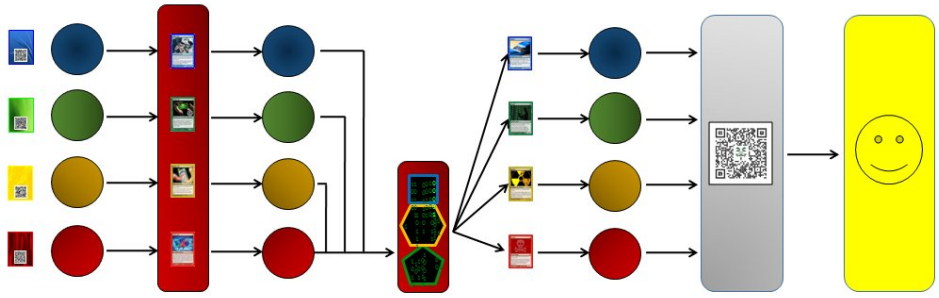

Figure 8. Breakout steps.

As an alternative, Figure 9 shows the breakout process after modifying the game to design it linearly with a unique path. Thus, teams compete against the rest during the entire game.

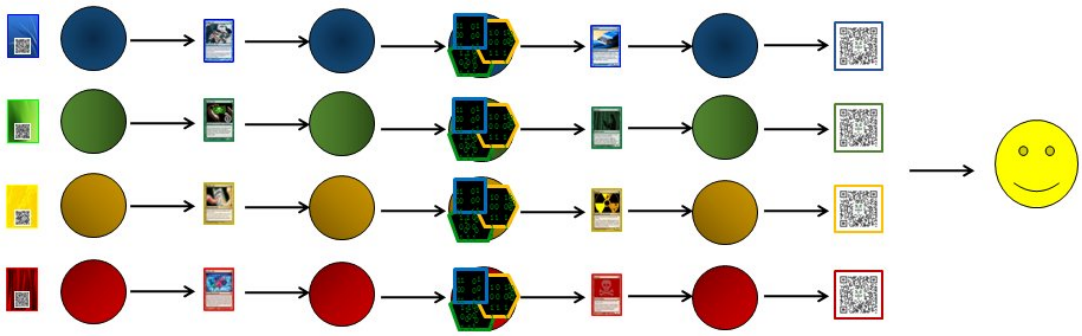

Figure 9. Modification of the breakout process to make it linear.

We have experimented our proposal with master degree students attending the master for secondary education and high school teaching (with specialization in mathematics); with undergraduate students attending a Cryptography course (optional subject from the Computer Science Engineering Degree), both at the University of Salamanca. This game has also been played by a group of 16 mathematics teachers that collaborate in the Rules_Math project (Erasmus+ project, co-financed by the European Union), and a group of 24 Linear Algebra teachers during a workshop.

Gamers' opinions and suggestions on the educational escape game were collected through onsite discussion and with an online survey (with Yes/No questions and some open questions) that was conducted immediately after the end of the activity.

The evaluation survey was completed by a total of 86 players: 46 students (19 from the first course of Calculus in the Industrial Engineering Degree, 10 from the third course of the Computer Science Degree, and 17 from the Master Degree), and 40 mathematics teachers (separated into two groups of 16 and 24).

The proposed survey includes some questions similar to those of [11], such as the organization of the game, the opinion of the gamer, and if it is possible to learn with such an activity. In our case 57% of players have never heard about these games, only 10% had previously participated in escape room games, 93% agreed that this game could be very useful in mathematics classes, and a similar percentage of individuals (92%) think that this could also be used in other subjects.

When gamers were asked about typical problems that could be solved with games, we got some interesting answers (mainly from the teachers that participated in the game): the computation of areas using integrals, the calculation of the shortest way to a destination, programming, logical problems, and mental challenges that can be solved without additional technology.

When we discussed the results of the game with university teachers, all of them understood the huge amount of time that preparing this type of activities requires (approximately 35–40 h). That is the main reason why many teachers are not planning to propose this activity to their students. One of those teachers commented that such activities are not suitable for university students.

It is necessary to clarify that, during the first instances of the experiment, the game was improved thanks to the experience acquired in previous occasions. In the first experiences, players needed more help from teachers. Thus, an important outcome is that it is important to adapt the difficulty of both the tests and the contents to the level of the players.

A key aspect for the proper functioning of the game is that each group of players work together as a coordinated team. Young people are more willing to participate in games than adults, even if the purpose is educational.

5. Conclusions

Game–based learning methodologies are increasing their applicability in higher education. Students are more motivated to learn mathematics and acquire mathematical competencies through gaming. It is possible to organize a problem-solving session as an escape room or breakout. We have proposed and conducted a breakout with engineering students to make them solve systems of linear equations, calculate the fundamental vibration mode, obtain the area of a surface (using integrals), or use Newton's law of cooling. Instead of solving those problems using a "classical" way, players learned it by using games.

During the different game sessions, we noticed that students usually did not review all the information that was available to them (sometimes we also find this when we propose them a "classical" problem with a long statement). They started playing and, when they did not know how to continue, they looked for additional information. As a consequence, after the first escape game session, we preferred to show players all the resources that were available for playing the game.

We have performed this experiment with master degree students from the master dealing with training future primary and secondary school teachers; with undergraduate students attending Cryptography (optional subject from the Computer Science Engineering Degree); with a group of 16 mathematics teachers that collaborate in the Rules_Math project (Erasmus+ project, co-financed by the European Union), and also a group of 24 Linear Algebra teachers during a workshop.

As a result, we noticed that players are very competitive, their primary goal being to win. The proposal depicted in Figure 9 obtained better results, though in this case students needed as much help as in the first proposal.

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