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# Examining the Use of an Educational Escape Room for Teaching Programming in a Higher Education Setting

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**ABSTRACT** In addition to being a well-liked form of recreation, escape rooms have drawn the attention of educators due to their ability to foster teamwork, leadership, creative thinking, and communication in a way that is engaging for students. As a consequence, educational escape rooms are emerging as a new type of learning activity under the promise of enhancing students' learning through highly engaging experiences. These activities consist of escape rooms that incorporate course materials within their puzzles in such a way that students are required to master these materials in order to succeed. Although several studies have reported on the use of escape rooms in a wide range of disciplines, prior research falls short of addressing the use of educational escape rooms for teaching programming, one of the most valuable skills of the twenty-first century that students often have difficulties grasping. This paper reports on the use of an educational escape room in a programming course at a higher education institution and provide, for the first time, insights on the instructional effectiveness of using educational escape rooms for teaching programming. The results of this paper show that appropriate use of educational escape rooms can have significant positive impacts on student engagement and learning in programming courses. These results also suggest that students prefer these activities over traditional computer laboratory sessions. Finally, another novel contribution of this paper is a set of recommendations and proposals for educators in order to help them create effective educational escape rooms for teaching programming.

**INDEX TERMS** Computer science education, educational escape rooms, educational technology, engineering education.

## I. INTRODUCTION

In recent years, escape rooms have become one of the leading leisure activities around the globe [1]. According to [2], escape rooms can be defined as "live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal (usually escaping from the room) in a limited amount of time". In addition to being a well-liked form of recreation, escape rooms have drawn the interest of educators due to their ability to foster valuable skills such as teamwork, leadership, creative thinking, and communication [3]–[8]. It may come as no surprise that educational institutions have started to integrate these initiatives into their programs, using escape rooms for educational purposes. Some instructors have taken one step further and created educational escape rooms, which can be defined as: "escape rooms that include part of the course materials within their puzzles in such a way that students are required to master these materials in order to solve the puzzles and succeed in the escape room".

Although one may presume that escape rooms are most suitable for the earlier stages of education, this sort of gamified experience is regarded as an attraction mainly for adults [2], making it a perfect fit for students in higher education. Several studies have reported on successful uses of educational escape rooms in a wide range of disciplines, especially in STEM courses [9]–[20]. Nevertheless, prior research falls short of addressing students' perceptions of using educational escape rooms for teaching one of the most valuable skills of the twenty-first century: programming. Insights on

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this hot topic would be of great help to better understand the benefits of using this kind of activities in programming courses, especially considering that many students find programming difficult to learn, as evidenced by the high failure rates that programming courses usually have [21].

This paper presents the results of a pilot experience of an educational escape room conducted in a programming course at a higher education institution. The educational escape room was designed to be used in large-enrollment programming courses. It featured a wide range of puzzles that incorporated programming challenges and combined both digital and physical resources, creating a multitudinous hybrid experience. A survey was conducted after the activity in order to collect students' opinions in terms of engagement, educational value, and design of the educational escape room. The results of this survey provide, for the first time, insights on the instructional effectiveness of using educational escape rooms in programming courses. Another unique contribution of this paper is a detailed set of recommendations for educators to help them create effective educational escape rooms for teaching programming.

The present paper is organized as follows. Existing literature on educational escape rooms is reviewed in the next section. Section III includes a comprehensive explanation of the designed educational escape room. Section IV explains how the educational escape room experience was evaluated. Section V shows and discusses the results obtained from this evaluation, and Section VI outlines the lessons learned from conducting the educational escape room and provides a set of recommendations for creating similar activities. Lastly, Section VII finishes with the conclusions of the paper and an outlook on future work.

## II. RELATED WORK

Because of the novelty of the concept of escape room, there is a paucity of research examining the use of educational escape rooms as well as the application of non-educational escape rooms in educational settings. There are a number of cases of demonstrated success in conducting educational escape rooms in higher education in the fields of nursing [9], [10], medicine [11], [12], pharmacy [13]–[16], physiotherapy [17], chemistry [18], computer networks [19], and mathematics [20]. However, to the knowledge of the authors, no works have been reported in the computer programming field. In addition to the previous ones, there have been other initiatives targeted to college students that foster informal learning such as earthquake-preparedness [22], or as a welcome activity for students to get to know institutional services [23], [24]. Some instructors have also conducted purely leisure escape rooms (whose puzzles do not integrate any educational content) with the sole aim of practising soft skills such as teamwork, leadership and communication [6], [7].

In most documented experiences of educational escape rooms, students form teams of 3-8 people and are given a limited time (usually one hour) to complete a series of puzzles and "break out" of a room, either literally or in a symbolic manner. Some works in the existing literature target groups with a reduced number of students, enabling the participation of all the students at the same time (e.g. [9], [12], [19]). When targeting large groups, some instructors were confronted with the necessity of conducting the activity in multiple time slots [10], [15], [20], [23], thus demanding a considerable investment of time and effort on the part of faculty members. Little research has been conducted to address the challenges of performing escape rooms in large-enrollment courses, allowing groups with numerous students to participate simultaneously. Among the few works that have addressed this topic are [13] and [14]. Designing an educational escape room to be conducted in a single session allows to significantly reduce the time investment when running the event, although this possibility is subject to the availability of a space that can fit all students concurrently and a sufficient number of faculty members, knowledgeable of the course materials and puzzle solutions, that can supervise the activity. This challenge is heightened in the case of escape rooms in which students need individual or per team equipment; for instance, in escape rooms that require students to use computers [14], portable devices [8] or virtual reality gear [4], [25].

One of the main challenges for escape room designers is to devise an interesting narrative and to build a series of puzzles that line up with it [2]. Generally, these puzzles require no special knowledge or skills, although sometimes they may include pop-culture references related to the theme of the room. Some examples of puzzles include searching for hidden objects, solving word puzzles, deciphering codes, or assembling physical objects [2]. In the case of educational escape rooms, the challenge of building puzzles becomes more complex for teachers [14], since they also have to integrate course materials within them in such a way that students only succeed in the escape room by mastering such materials. Therefore, teachers need to create puzzles that fit seamlessly within the narrative of the escape room while covering the key competencies taught in the course. Various types of puzzles used in educational escape rooms have been reported in the literature, including puzzles that require students to calculate medication dosages [9], [13], analyze lab results [11], perform chemical experiments [18], make use of mathematical software [20], decipher encrypted information and sniff network traffic [19]. In view of these previous experiences, the nature of the puzzles used in educational escape rooms seems to be highly dependent on the subject area.

Another key challenge for creating an escape room is to adjust the difficulty level of the puzzles, which is not an easy undertaking for escape room designers [2]. This challenge is even more complex in educational puzzles, where this adjustment needs to be done by taking into account both the difficulty to understand the puzzle mechanics and the difficulty to master the course materials. In educational escape rooms, complexity plays a crucial role in the success of the experience, since exceedingly easy puzzles will soon bore students whereas, if the difficulty level is set too high, it can lead to frustration or even anxiety [13]. The majority of prior works did not provide information about the success rate for educational escape rooms (i.e. what percentage of students solved all the puzzles before the time runs out). Some of them reported that none of the students was capable of breaking out of the room in time [13], whereas, at the other end of the spectrum, others stated that all of them did [11]. This type of data is essential in order to evaluate the difficulty of the activity with a view to modulate it for subsequent editions. None of the previous studies on the topic set out to determine which success rate results in an optimal trade-off between boredom and frustration. Existing literature on gamification (e.g. [26]) proposes to follow Csikszentmihalyi's flow theory [27], which suggests maintaining the players in a total immersion state in which they are neither overchallenged nor underchallenged. An approach that is also suggested consists of increasing the difficulty from one puzzle to the next one [28]. Being stuck at the very first puzzle can be very discouraging for escape room participants. On the contrary, if the bottleneck is on one of the last puzzles, the feeling of frustration is not the same, since it has been preceded by an adrenaline rush from solving all the previous ones.

Another disregarded topic in the literature is the management of hints and communication between students and instructors in educational escape rooms. Research papers that addressed this topic reported that either hints were provided on demand when students got stuck [19], [20] or when instructors considered it necessary [10]. Other popular alternatives consist in distributing a limited number of hint cards upon which the students can draw to get assistance [15], [13], or applying a time penalty every time they call for help [17], [9]. Most works reported that faculty members supervised students throughout the course of the activity by being present in the same space, although some of them actually involved students being alone in a locked room. The latter approach often included video vigilance to monitor the activity [15], [19], or even walkie-talkies to allow communication between students and instructors [19].

When addressing students' perceptions of educational escape rooms, prior studies found that students enjoyed participating and, at the same time, they considered them a valuable learning experience [10], [13], [15]. Previous studies also found that students prefer educational escape rooms over regular classroom experiences [14], [15]. Other interesting findings of one of these works [15] are that educational escape rooms can help students learn from their peers and see the course materials from a different perspective. It should be remarked that no article was found in the literature examining the effect on students' perceptions of using educational escape rooms in programming courses. This specific application of educational escape rooms poses additional challenges for instructors since learning programming is hard for many students [21] and usually involves using digital resources which can be complex to integrate into these immersive experiences.

## III. DESCRIPTION OF THE ESCAPE ROOM EXPERIENCE

This section explains in detail the educational escape room that we conducted in a programming course at a higher education institution.

### A. CONTEXT

The course in which the educational escape room was conducted is part of the Bachelor's Degree in Telecommunications Engineering from UPM (Universidad Politécnica de Madrid), and it is a fourth-year elective taken by students majoring in Telematics that accounts for 6 ECTS (European Credit Transfer System) credits, equivalent to 150-180 hours of student work. One of the main blocks of this programming course is about front-end development, in which students review the basics of HTML, CSS, and JavaScript, and learn React [29], Redux [30] and React Native [31]. React is a JavaScript library for building web user interfaces. React Native is a framework that allows building native mobile applications using React. Lastly, Redux is a JavaScript library for handling the application state that can be used with React and React Native, among other technologies. The aim of the conducted educational escape room was to reinforce the most important concepts covered in this block of the programming course.

The main motivation of the course staff for introducing the educational escape room was to increase the low pass rate (56%) that this block of the subject had in the previous year through an activity capable of successfully engaging students. During this block, theory lectures are interspersed with 2-hour computer lab sessions aimed at helping students enhance their programming skills, review the main concepts and dispel doubts. Instead of conducting an additional lab session to try to increase students' academic performance, the course staff decided to organize an educational escape room seeking a more motivating activity that yields tantamount learning effectiveness.

The educational escape room was offered to all the students of the course as an optional but graded activity. It was not mandatory for students to participate, but it counted around 5% toward the final grade of the front-end development block. The activity was graded on a scale of 0 to 10. Students who attended the escape room earned 7 points just for participating in it and, in addition, those who were capable of successfully solving all the puzzles in time were given the 3 remaining points. The educational escape room was conducted in December 2018, a few days prior to the final exam. Of the 136 students enrolled in the course, a total of 124 attended the educational escape room. This figure represents around 91% of the students enrolled in the course and nearly 98% of the students who took the final exam of this block of the course.

### B. DESIGN

The educational escape room was conceived as a hybrid experience in which students had to solve a combination of computer-based and physical puzzles in a limited amount of time while immersed in an engaging narrative (which is detailed in section III-C). The puzzles of the escape room were arranged in a sequence in such a way that each puzzle unlocked the next one (section III-D describes each of the puzzles used in detail). Thus, students were required to solve the puzzles in a specific order. Using puzzles that follow a sequential path is a common schema for escape rooms [2], as it requires the whole team to engage in the puzzles simultaneously. This is preferable from a pedagogical point of view, since it demands that all students work on the entirety of the concepts covered in the escape room. In escape rooms for teaching programming, this schema also promotes taking advantage of the benefits of pair programming [32], [33] if students are tied in pairs. Moreover, sequential escape rooms are often easier since they require less guidance, thus making it simpler for students to progress. These escape rooms also allow the course staff to track the activity in a more simple and accurate way since the progress and performance of all students can be measured more easily. The designed educational escape room combined computer-based and physical puzzles. Digital puzzles may require students to understand, write and/or execute programming code in real time, thus allowing for more complex challenges to test and improve their programming skills, whereas physical puzzles are of great help for enhancing both the immersion of the experience and student engagement. The aim of combining both types of puzzles was to create a highly engaging activity for teaching programming without compromising its educational value.

In educational escape rooms, it is essential to prevent students from getting stuck at one puzzle for too long. Otherwise, students can get bored, frustrated or even angry. In addition, this may be detrimental from the pedagogical point of view since it keeps students from attempting all the puzzles. As mentioned before, in order to deal with this issue, educational escape rooms generally give hints on demand when students get stuck or when instructors consider it appropriate, sometimes applying time penalties. In this experience, we decided on an innovative approach for managing hints. Instead of giving hints for free or at the cost of a time penalty, we decided to adopt an approach in which students have to earn the right to get help from the instructors by passing a small quiz delivered through a web application. This quiz is comprised of five questions on the course content randomly selected from a pool of questions from past exams, questions from a MOOC (Massive Open Online Course) developed by UPM, and new questions added by the teachers. Students have to get at least four out of five answers right in order to receive help from the instructors. Students can attempt to solve quizzes as many times as they wish through the hint application. Therefore, after passing a quiz and getting a hint, students can try to pass another one in order to get a new hint. Although there is no limit to the number of hints a student can demand, this approach does not lend itself to allow continuous help requests, since earning a hint requires an investment of time, a scarce resource during an escape room. Furthermore, this approach fosters that students review the theoretical content of the course, complementing the practical programming skills the escape room aims to improve. An interesting feature of the hint application developed is that the pool of questions can be easily modified through a configuration file without a need to have strong technical skills, making it straightforward to reuse the same application in subsequent editions or even in educational escape rooms conducted in other courses. It should be noted that students were allowed to consult the course materials as well as to access the Internet during the whole activity in order to solve the puzzles and to answer the questions in the hint application.

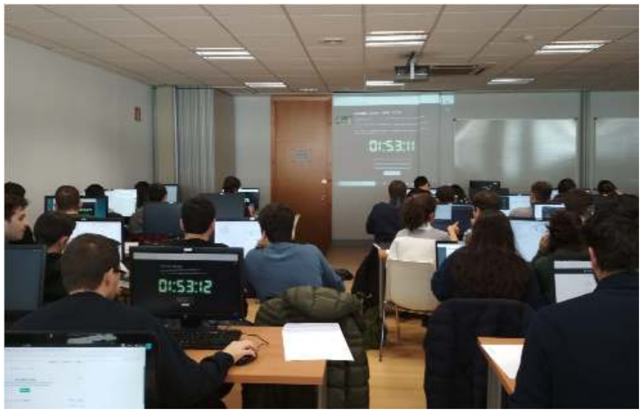


**FIGURE 1. Students in the computer lab during the educational escape room.**

The educational escape room was designed in such a way that it enabled the participation of all students in the course at the same time. In order to accomplish this, the activity was hosted at a large computer laboratory (see Fig. 1) and all puzzles were designed to be replicated in an easy and inexpensive way. Performing the escape room for many students at the same time allows to decrease the time investment for the course staff. Besides, it prevents students from receiving information about the activity from other students that performed it before. Since there is a dearth of research work addressing the challenges of allowing all students of large-enrollment courses to participate in educational escape rooms simultaneously, the proposals and recommendations exposed in this paper are also an important contribution to the literature. In this experience, instead of forming large teams, students were told to team up in pairs which, to the knowledge of the authors, has not been attempted in any preceding educational escape room experience. Prior research substantiates the belief that pair programming increases learning outcomes, reduces student frustration, and improves the overall quality of the resulting code [32], [33]. A recent study carried out on people's behavior in escape rooms [3] also found that teams comprised of two people saw fluctuation in terms of leadership, whereas in large teams the same person usually kept the leading role throughout the activity. Before starting the escape room activity, a laboratory desk with a computer and a unique code was assigned to each participating team.

A total of three course teachers were present during the activity in order to supervise it and to give hints to the students following the aforementioned approach.

The educational escape room was designed to last two hours, the typical duration of a computer lab session. Thus, students had two hours to solve all the puzzles. As mentioned before, educational escape rooms do not generally last more than one hour. However, we decided to set the duration of the activity to two hours because we strongly believe that meaningful programming challenges require more time and effort to be solved. Furthermore, two hours is also the typical duration of computer lab sessions, hence allowing the course staff to easily replace a lab session with an educational escape room activity in the course instructional design. At the end of the escape room activity, all students were encouraged to get their picture taken at a photocall assembled for the event, which included a chroma key with a dungeon as its background, along with a few other props.

The main aim of conducting the educational escape room was to provide an engaging activity beneficial for the students' learning. Taking into account that students were encouraged to study the course materials in advance in order to solve the puzzles, it could be reasonable to think that the educational escape room could only be used as a reinforcement activity. However, it should be remarked that students were expected to acquire new knowledge and improve their practical programming skills in the educational escape room by learning from their peers and as a result of the resolution of the puzzles and the completion of quizzes in the hint application. Moreover, this activity was also intended to allow students to identify aspects into which they need to further dwell that would otherwise remain unnoticed.

The process followed by the course staff to create the educational escape room was composed of eight steps. First, the approach for incorporating the activity into the course, as well as its requirements and general design, were broadly discussed and defined. In this first step, it was decided that the educational escape room would be offered as an optional but graded activity, that it would last two hours, and that it would enable the simultaneous participation of all students of the course teamed up in pairs. In this step, other design aspects were also determined, including the decision to combine computer-based and physical puzzles, the arrangement of the puzzles in sequence, and the use of the hint approach previously explained. In the second step, the main learning objectives of the front-end development course block were identified. After that, a discussion was carried out in order to decide which kind of puzzle would be more appropriate to address each learning objective identified in the previous step, and how many puzzles the educational escape room should have considering its duration. Afterwards, a narrative for the experience was proposed based on this discussion, and its storyline was concocted. Then, the puzzles, clues and the rest of the resources needed to conduct the escape room experience (e.g. the introductory video) were elaborated. In this regard, it is worth pointing out that the puzzles needed to line up with the narrative, integrate the appropriate course materials to address their corresponding learning objective, and entail a reasonable difficulty so as to achieve a suitable trade-off between boredom and frustration. In order to accomplish this last requirement, it was essential to take into account the effect of the difficulty not only of the puzzle mechanics but also of the learning objectives. As suggested in [26] and [28], the puzzles were designed to be of increasing complexity, the last puzzle being the most difficult one. In fact, in spite of following a sequential path for the whole escape room, the last puzzle had an open structure in order to increase intricacy. This puzzle was composed of three sub-puzzles that students needed to solve in no particular order so as to finally succeed in the escape room. After the elaboration of the puzzles, each of them was individually tested to ensure correctness. Then, the whole educational escape room was tested through a simulation with one faculty member (knowledgeable of the course materials) who volunteered to participate. Finally, some minor refinements were made to the escape room based on the lessons learned from the simulation and the participant's feedback.

**FIGURE 2.** Screenshot of the introductory video screened to students at the beginning of the escape room.

### C. NARRATIVE

The overall theme selected for the narrative of the educational escape room was deactivating an explosive artifact, which is a popular topic, accounting for 5% of escape rooms worldwide [2]. The activity started by presenting the students with an introductory video (Fig. 2) screened on the computer lab in which one person appears in the middle of a dungeon, in an uncomfortable chair, hands and legs tied. In the video, this person presents himself as ''the professor'' and explains that he has discovered that some teachers from the electronics department were building a bomb to blow up the whole school and they found out that he was developing a software application to deactivate it. The professor also says that he was kidnapped before finishing the software application and, since this application was based on the technologies that students learned in class, they were the only ones capable of completing it in order to stop the bomb and save him and the whole school. He also reveals to the students that he has hidden a few clues in an envelope to help them finish the software application and warns them that these clues are encrypted in order to prevent the evil teachers from the electronics department from understanding them. This gives a purpose to the escape room puzzles, which is in line with the "Ask Why" model for designing escape rooms proposed in [28]. This model advocates that all the elements in a room should be included for a reason that is consistent with the narrative, and not just for the sake of adding difficulty. After watching the video, students are given two hours to run the bomb-deactivating application before the bomb is detonated at the end of the countdown. This countdown is projected on a screen during the whole activity allowing students to be aware of the time they have left to deactivate the bomb at any moment. The experience reported in this work is a case of a reverse escape room, in which students are not locked in a room but, instead, they need to help a kidnapped person break out. This approach allows enhancing the immersion of the experience since students find it easier to put themselves in this situation in comparison with an escape room whose narrative presumes they are actually locked up. Undoubtedly, the psychological conditions of being confined in a closed room are different from those of being in a laboratory with dozens of other students around. Nevertheless, the latter does not prevent the experience from being considered an escape room, since it incorporates the key elements that are distinctive of these activities: an engaging narrative that articulates the whole experience, a series of puzzles intended to be solved collaboratively that rely on game mechanics, and the feeling of rush due to the countdown. Having all the teams together in an unlocked room is not something unique to this experience, as it seems to be the go-to approach for designing educational escape rooms that can fit all the students simultaneously in large-enrollment courses according to [13] and [14]. Moreover, although escaping from an actual room is the most common theme in escape rooms, a number of them revolve around completely different narratives [2]. On this point, the narrative of the experience presented in this work combines five overarching concepts used in leisure escape rooms: escaping a specific unpleasant place such as a dungeon (which accounts for 30% of escape rooms worldwide), defusing an explosive device (5%), freeing another person (2%), helping create something (2%) and surviving (1%) [2].

### D. PUZZLES

Table 1 summarizes all the puzzles that were integrated into the educational escape room activity indicating, for each one of them, the learning objective addressed and the puzzle mechanics used. The terminology employed for naming these puzzle mechanics has been primarily extracted from [2], although some new terms have been incorporated. All the puzzles are described in detail in the next subsections.

**TABLE 1. Summary of the escape room puzzles.**

| Puzzle No. | Learning objective | Puzzle mechanics |
|---|---|---|
| 1 | Use GitHub for downloading a code repository | – Noticing something obvious in a room |
| 2 | Understand the "package.json" file of a React application and start that application | – Using something in an unusual way |
| 3 | Debug a React application using the web browser console | – Fixing something that is broken |
| 4 | Invoke JavaScript functions | – Hearing<br>– Researching using information sources |
| 5 | Render lists in React using the map function | – Translating<br>– Modifying something |
| 6 | Know the React lifecycle methods | – Noticing something obvious in a room<br>– Searching for objects in images<br>– Pattern identification |
| 7a | Understand the Flexbox layout mode | – Symbol substitution |
| 7b | Know the Redux architecture | – Assembly of a physical object<br>– Shape manipulation<br>– Pattern identification |
| 7c | Review HTML, CSS and JavaScript basics | – Riddle<br>– Shape manipulation<br>– Symbol substitution |
| 7d | Perform an asynchronous request to a REST API | – Communication with an entity outside the room |

#### PUZZLE 1: DOWNLOADING THE BOMB-DEACTIVATING APPLICATION

Each team participating in the educational escape room had an assigned laboratory desk with a computer, on top of which there was an envelope. In the introductory video, students are told that this envelope contains several clues to help them finish the bomb-deactivating application. The first clue that students find inside the envelope is a piece of paper with an IP address written on it. This IP address points to a landing website where they can find the introductory video, a link to the hint application previously described, and a link to a GitHub repository that hosts the bomb-deactivating software application. Using GitHub in educational settings has become popular in recent years since it is an outstanding tool to foster collaborative learning [34] and to facilitate teamwork while enabling traceability of individual contributions [35]. Knowing how to download code from this platform to their own computer constitutes the first challenge of the escape room for the students and, from the educational point of view, the first learning objective.

#### PUZZLE 2: STARTING THE BOMB-DEACTIVATING APPLICATION

Once students have downloaded the code of the bomb-deactivating application, they should identify that it is indeed a React application, such as the ones with which they have worked in class. Their next goal is to properly install all the dependencies and run the application. The most common command to run a React application is "npm start" but, in this case, when students run it they are faced with an error message that urges them to find the right command for this application. For this puzzle, students need to know that, in this kind of applications, available scripts are listed in the "package.json" file. By inspecting this file, they identify that the right command is "npm run breakout". After running it, students are presented with visual feedback that the application is working, which is important for them to know that they are on the right track.

### PUZZLE 3: LOADING THE FIRST SCREEN

The bomb-deactivating application has some intentional errors that students need to fix so as to load the first screen of its web interface. In order to track down these errors, they need to know how to debug code using the web browser console, which is a skill that is important to all programmers, especially novices [36]. There is a total of three errors, which deal with basic knowledge of React: importing dependencies, knowing that all React components must define a render method, and realizing that the render method can only return one element.

### PUZZLE 4: ADVANCING TO THE SECOND SCREEN

Once all errors have been amended, students are presented with the first screen of the bomb-deactivating application on the browser. It contains a welcome message that warns them that, in order to access the advanced features, they need to execute the function specified in an audio track embedded below. Hearing is a technique that is used in 26% of escape rooms worldwide [2] to potentiate immersion. In this case, the audio track consists of the Morse code distress signal ("SOS"). Students need to decode the message and call a function named "SOS" in order to continue to the next screen. This task allows them to review the idea that, in JavaScript, functions are declared as variables and need to include parentheses in order to be invoked. Students are not expected to be familiar with Morse code but instead, they should use online information sources in order to overcome this challenge. There is evidence that 20% of escape rooms require participants to research using information sources [2].

The progress of the students towards the bomb-deactivating web application is saved using the browser's local storage in order to preserve it even if students refresh the webpage. Thus, it is guaranteed that a team should not solve the same puzzle more than once and that the proper screen will be presented if the application is reloaded. Moreover, in order to avoid cheating, most of the code that manages the progress of the bomb-deactivating application is intentionally obfuscated, so students are not capable of understanding it.

### PUZZLE 5: SHOWING THE BOMB PARTS

The next screen in the application has a message in an unknown language. Students need to make use of an automated translation engine in order to find out that it is Bengali language and to interpret its meaning. The text appeals to them to modify the application's code in order to render a list of React components that constitute the different bomb parts. The standard way of doing this in React is by using the "map" function, a concept that was strongly highlighted in class and that students often have difficulties grasping. If students correctly perform said programming task, four toggle switches appear on the screen (as seen in Fig. 3), each one associated with one part of the bomb.

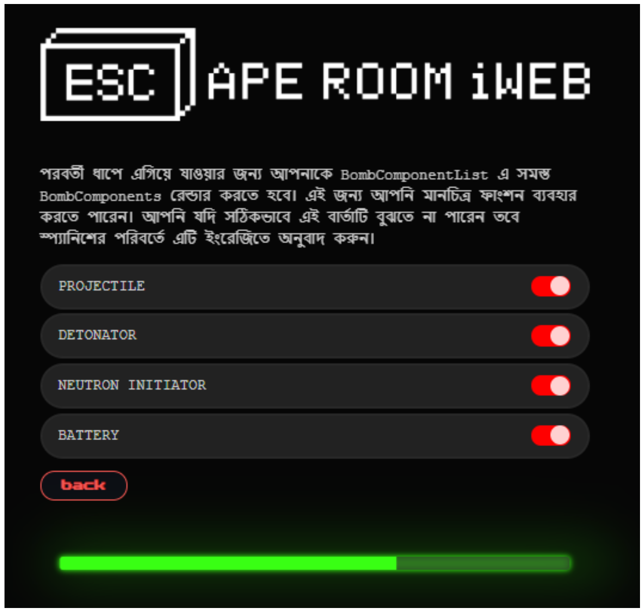


**FIGURE 3.** Screenshot of the bomb-deactivating application.

### PUZZLE 6: DEACTIVATING THE BOMB PARTS

In order to solve this puzzle, students need to turn off the switches associated with the bomb parts revealed in the previous step in the right order, mimicking the deactivation of the different bomb components. In order to find out the right sequence, they need to use one of the clues left in the envelope. Specifically, they need to examine a picture of the professor's office and notice a drawing on the blackboard that establishes a parallelism between the bomb components and some of the React lifecycle methods. By putting the lifecycle methods in order, students find out the right sequence for deactivating the bomb components. This puzzle combines three widely used resources in escape rooms: noticing something obvious in a room, searching for objects in images, and pattern identification. These puzzle mechanics are used respectively in 49%, 43% and 38% of escape rooms worldwide [2].

### PUZZLE 7: TRIGGERING THE COOLING MECHANISM

At this point, students think they have already accomplished their final goal, but they suddenly encounter an unforeseen event: the bomb's uranium core is overheating. The element of surprise is a technique often used as a part of good storytelling and solid game design [37]. In order to trigger the cooling mechanism, students need to perform an asynchronous call to a REST API. First, they need to find out the port number on which the API is listening by solving three sub-puzzles (7a, 7b and 7c). After that, they must code the corresponding asynchronous request (sub-puzzle 7d).

#### *PUZZLE 7a: FLEXBOX*

Once again, students need to refer to the paper-based clues included in the professor's envelope in order to find out the missing information. This time, they are provided with the code of a React Native application which consists of a grid made of colored squares. Students need to have an understanding of Flexbox (the layout mode used to build interfaces in React Native) and apply symbol substitution (a technique used in 47% of escape rooms [2]) in order to figure out the right order for the colors. Only one color in each row will eventually reveal the number of the port. They need to solve the puzzles 7b and 7c to find out which one.

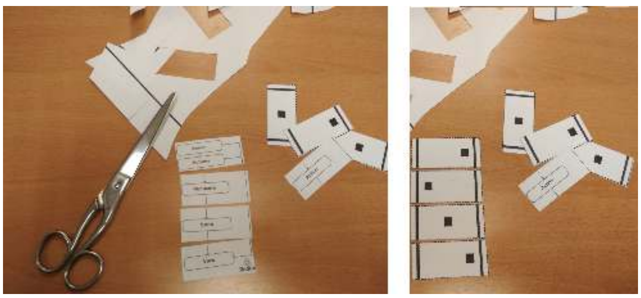

**FIGURE 4.** **Redux architecture jigsaw.**

#### *PUZZLE 7b: REDUX ARCHITECTURE*

For this puzzle, students need to make use of a piece of paper contained in the envelope which has several jigsaw pieces (see Fig. 4). Each of these pieces contains the name of an element that is susceptible to being part of the Redux architecture. Students need to cut out all the pieces and put them in the right order, discarding those that are not part of said architecture. Assembling a physical object is a recurring technique used in 40% of escape rooms around the globe [2]. Once they solve the jigsaw, they can flip it over and see that each row has one square aligned to the left, to the right or centered. Using shape manipulation is required by 11% of escape rooms [2]. The resulting square disposition corresponds with the color grid from puzzle 7a. Students can obtain a list of four colors by filtering out only one color for each row.

#### *PUZZLE 7c: HTML, CSS AND JAVASCRIPT BASICS*

This challenge deals with discovering what number is associated with each color, in order to discover the port number. Students find another piece of paper inside the envelope, which contains the code of an HTML page that requires them to evaluate a snippet of JavaScript code that tests their knowledge on conditionals, loops, arrays and also on CSS selectors and basic HTML. The resulting rendering of the HTML page reads: ''In order to solve the puzzle, green must face north''. Students need to scan a QR code present in the sheet of paper, which takes them to a digital numbered color roulette with twelve different colors. Each color is lined up with a number that changes when the roulette is rotated. Students need to rotate it until the green color faces north to obtain the correct correspondence between numbers and colors. Putting all the information from puzzles 7a, 7b and this one together, the four-digit sequence corresponding to the port number is finally unveiled. Using riddles like the one involved in this puzzle is quite common in escape rooms, accounting for 37% of them [2]. Moreover, solving this puzzle requires using symbol substitution and shape manipulation (rotating the roulette).

#### *PUZZLE 7d: ASYNCHRONOUS REQUEST*

Finally, once students obtain the port number (by solving puzzles 7a, 7b and 7c), they may perform the asynchronous request to the REST API. In the body of the request, they must include the team number that they were assigned before the event. Once the request has been successfully performed, the cooling system is launched, thus ending the explosive threat and concluding the escape room activity.

The web server where the API is hosted records students' submissions along with the remaining time, allowing the course staff to keep track of those students who successfully complete the escape room, which is no easy task on such a large gathering of students.

## IV. EVALUATION METHODOLOGY

Students' opinions on the performed educational escape room were collected through an online survey that was conducted immediately after the end of the activity. This survey included some initial demographic questions, a set of opinion questions, and a list of statements with which students needed to agree or disagree using a 5-point Likert scale. The questions aimed to assess the students' perceptions toward the use of the educational escape room as a learning activity, the students' thoughts on the design of the escape room, and whether students preferred the escape room over a regular computer lab session. At the end of the survey, there was a space in which students could leave suggestions, complaints, and other comments.

The main aim of this study was to evaluate the students' perceptions of the conducted educational escape room. In order not to influence these perceptions, no pre-test was conducted prior to the beginning of the activity. Performing a pre-test and a post-test would have allowed obtaining a quantitative measure of learning effectiveness. However, this intervention could have caused an impact on the students' motivation since filling a questionnaire is perceived as a cumbersome task by many of them. Moreover, having a randomized control group was not possible in this study due to ethical reasons and the university's policy. Therefore, in this

**TABLE 2.** Results of the educational escape room survey conducted among students.

| Question | N | M | SD |
|---|---|---|---|
| What is your general opinion on the escape room? (1 Poor - 5 Very Good) | 84 | 4.3 | 0.8 |
| Please, state your level of agreement with the following statements (1 Strongly disagree - 5 Strongly agree): | | | |
| In general, I like to play games (video games, board games, etc.) | 83 | 4.2 | 0.9 |
| The front-end development part of the course has been easy for me | 83 | 3.0 | 1.0 |
| The escape room allowed me to improve my knowledge of the course materials | 82 | 3.4 | 1.2 |
| The escape room was fun for me | 84 | 4.2 | 1.1 |
| The escape room was too difficult | 82 | 3.4 | 0.9 |
| The escape room was well organised | 83 | 3.9 | 1.0 |
| I liked the escape room better than a computer lab session | 82 | 4.5 | 0.9 |
| I learned more with the escape room than I would have with a computer lab session | 79 | 3.7 | 1.3 |
| | | Yes | No |
| Would you recommend other students to participate in the escape room (even if it was not for a grade)? | 84 | 76<br>90.5% | 8<br>9.5% |
| Would you like other courses to include activities like this (even if it was not for a grade)? | 84 | 80<br>95.2% | 4<br>4.8% |

case study, learning effectiveness was assessed in a qualitative way by asking students about their self-perceived increase in knowledge.

Prior research has found that educational escape rooms can be an effective way to foster student engagement in several disciplines [9]–[20]. Before conducting this study, we believed that its results would confirm that educational escape rooms can be an excellent fit for programming courses as well.

## V. RESULTS AND DISCUSSION

The evaluation survey was completed by a total of 84 students, who volunteered to do so at the end of the activity. This sample represents 67.7% of the 124 students who attended the educational escape room. Of the 84 students of the sample, 61 were male (72.6%) and 23 were female (27.4%). The mean age of respondents was 22.2 with a standard deviation of 2.9. Table 2 shows the results of the evaluation survey including, for each question, the mean (M) and standard deviation (SD), along with the number of answers (N).

In general, students regard the front-end development part of the course as the most challenging one. When inquired about this issue, they neither agreed nor disagreed with the statement that this course block was easy ($M = 3.0$, $SD = 1.0$). As it has been mentioned, the difficulty inherent in this part of the subject was the main motivation for running the escape room.

Most students expressed a prior interest in games ($M = 4.2$, $SD = 0.9$), although a gender bias was detected on the answers to this question by means of a Mann-Whitney U test. Males showed a high inclination towards gaming ($M = 4.4$, $SD = 0.7$), whereas females showed a statistically significant ($p < 0.001$) lower interest ($M = 3.6$, $SD = 0.9$). However, no gender bias was detected in any of the questions that addressed students liking of the escape room. These findings indicate that, although females seem to have reservations with regard to games in general, the escape room attracted students of both genders equally. As a matter of fact, Nicholson [38] found that around 70% of escape room teams worldwide are of mixed genders, and the remaining are equally split between all male and all female. Additionally, Chapman and Rich [39] reported that gender was not a barrier to finding gamification motivating.

The results of the survey conducted in this study show that students had a very positive overall opinion on the educational escape room ($M = 4.3$, $SD = 0.8$) and thought it was a fun experience ($M = 4.2$, $SD = 1.1$). Students' prior interest in games proved to be no harbinger of their opinion on the escape room since no correlation was found between these two variables. A percentage of 90.5% of students stated they would recommend other students to participate in the escape room and 95.2% claimed that they would like other courses to embrace similar activities. The satisfactory outcomes obtained for student engagement confirm the initial hypothesis of the present study that educational escape rooms can be an excellent way to foster motivation in programming courses, as foreshadowed by the results shown in prior works from other disciplines [10]–[20].

In regard to learning effectiveness, students stated that the escape room helped them improve their knowledge of the course materials to some extent ($M = 3.4$, $SD = 1.2$). These results were consistent with previous studies, which also found that educational escape rooms have the ability to improve students knowledge on a specific topic [10], [15]. Interestingly enough, all the students that reported very high learning outcomes also rated the activity as extremely fun. In fact, a moderately strong correlation (Pearson's $r = 0.62$, $p < 0.001$) was found between student engagement and self-perceived learning effectiveness. However, a non-negligible correlation was also found between learning effectiveness and whether students regarded the front-end development block as easy (Pearson's $r = 0.45, p < 0.001$), indicating that students that were already comfortable with the material were the ones who made the most of the escape room. Taking into account the results obtained on learning effectiveness, it can be stated that the educational escape room conducted was perceived by the students as a highly engaging and reasonably effective learning activity. Although one could presume that the educational escape room would not work as a teaching activity, since students were encouraged to review the course content beforehand, these results reveal that it allowed them to improve their prior knowledge of the course materials. Another indicator of the impact of the conducted educational escape room on the students' learning is the difference between the pass rate of the front-end development block exam of the students who attended the escape room ($N = 118$, Pass rate $= 79\%$) and that of those students who took the course the preceding year and hence did not have the opportunity to participate in said escape room ($N = 101$, Pass rate $= 56\%$). This difference was found to be statistically significant (chi-square test, $\chi^2 = 22.2$, $p < 0.001$). The difference in the average grade was also found to be statistically significant ($p < 0.001$) with a medium to large effect size (Cohen's $d = 0.75$) according to Cohen [40]. However, it should be considered that there were other factors that influenced the students' performance. For instance, although the exams of these two years covered the same topics, their content was completely different for obvious reasons. Therefore, it is not realistic to state that the improvement of students' performance was only due to the inclusion of the educational escape room.

Regarding the design of the escape room, students thought it was well organized ($M = 3.9$, $SD = 1.0$) and slightly agreed with the statement that it was too difficult ($M = 3.4$, $SD = 0.9$). Nevertheless, only 5 teams (8% of students) were capable of solving all the puzzles in the given timeframe, which might be an indicator of excessive difficulty. Prior works have also reported low success rates [13], [20], sometimes leading to students feeling frustrated that they did not have enough time to complete the activity. However, a few studies reported that all of the students were capable of breaking out of the room in time [11], [17]. Contrary to what could be expected, no correlation was found between the perceived difficulty of the escape room and student engagement (whether they thought it was fun). No prior studies, to the knowledge of the authors, have found a strong relationship between these two variables.

When compared with the computer lab sessions performed in the course, students declared that they prefer the escape room over a lab session ($M = 4.5$, $SD = 0.9$) and that the learning outcomes are somewhat higher in the former ($M = 3.7$, $SD = 1.3$). These results are consistent with previous research works [14], [16], which established that students feel more engaged and obtain slightly better learning outcomes in educational escape rooms than in other practical activities. In view of these results, course staff of programming courses at higher education institutions should consider replacing some hands-on activities, such as lab sessions, with well-designed educational escape rooms.

At the end of the survey, there was a space for comments, suggestions, and complaints. One student suggested having time limits for each puzzle so nobody gets stuck at the beginning, allowing more students to finish in time. In order to prevent students from getting stuck at a certain puzzle in our educational escape room, we allowed students to get hints by passing a web-based quiz. Notwithstanding, it seems that this hint approach was not sufficiently effective for some participants. Another proof of this issue was the complaint of a student who said that requiring to get four out of five answers right in the hint application was excessively demanding. There are a number of options that could alleviate this issue such as giving free hints for lagging students, disclosing hints to all participants at specific time points (as reported in [10]), making the first puzzles even easier, or making the different hints systematically given to students for the same puzzle increasingly helpful.

A few students also stated that the hardest part was knowing what to do first and that further guidance was needed at the beginning. This finding is consistent with those of prior research [13]. In view of this evidence, educational escape room designers should pay special attention to the starting point of the activity in order to provide students with sufficient initial guidance, in such a way that they are clearly aware of the final goal to be achieved, the first actions they should carry out and how they can ask for help when stuck.

A couple of students complained about not knowing if a certain error in the provided software application was intentionally introduced as a part of the escape room or was accidental, which added difficulty to the whole experience. This matter evidences that using software applications in educational escape rooms for programming courses poses additional challenges which are specific to this field. Using software applications as part of an educational escape room experience requires teachers to test them very carefully as well as to think thoroughly how to prepare them (e.g. by introducing errors or leaving incomplete parts) so as to be of high educational value for students. One drawback of escape rooms that include intelligent or interactive computer-based systems is that they require organizers to have significant technical expertise in order to design, develop and maintain the software involved.

Several students regretted not having reviewed the course materials in depth prior to the activity, underlining that mastering the course materials was the key to making the most of it. An earlier study has also come across this situation despite having warned students in advance that basic knowledge on the course content was needed in order to succeed in the activity [17]. It is suggested that instructors further dwell on this issue, finding ways to motivate students to review the materials before the educational escape room takes place. In this regard, offering an educational escape room as a graded activity could be helpful to achieve this aim. Furthermore, two students reported that they did not fully understand some of the course content covered in the escape room and asked to see it in more depth in class, a petition that was granted the following day.

Overall, most students left very positive comments in which they wrote that they thoroughly enjoyed the educational escape room experience and that they would like more hands-on activities like this one. They remarked they wished other courses undertook similar initiatives and thanked the course staff for taking the time to organize the activity. In general, students showed a high level of engagement in the course of the educational escape room and, when it came to an end, they provided highly positive face-to-face feedback and were eager to ascertain the correct answer to all the puzzles they could not solve in time.

## VI. LESSON LEARNED

This section presents several recommendations derived from the lessons learned from conducting the educational escape room previously described. Given that no previous educational escape room experiences in the field of computer programming have been reported in the literature, these recommendations constitute a valuable source of information for educators interested in creating effective educational escape rooms for teaching this subject.

The first valuable lesson learned is that it is of crucial importance for educational escape rooms to provide students with strong initial guidance since the initial confusion may cause them to lose a significant amount of time at the beginning, which may lead to frustration [13]. In order to tackle this issue, the initial guidance should clearly indicate the final goal of the escape room, the first actions that participants should perform, and how they can ask for help if they get stuck at one puzzle. Another useful recommendation is to make the first puzzles of the escape room very easy to further facilitate participants getting started with the activity.

Based on the results obtained from our educational escape room experience, we strongly recommend combining computer-based and physical puzzles when designing an activity of this kind in a programming course, which has proven to be an effective approach in other disciplines as well [8], [14], [19], [20]. On the one hand, digital puzzles allow presenting students with effective challenges that test and improve their programming skills. In this regard, we found especially useful using software applications with intended errors and/or incomplete parts carefully designed to be of educational value. Nonetheless, it should be noted that the development of these applications requires careful pedagogical design and thorough testing. On the other hand, physical puzzles have proven to have very positive impacts on student engagement and are very helpful for enhancing the immersion of the experience. The main reason for this is that these puzzles allow for the incorporation of mechanics into the activity that are not possible to provide through digital challenges, such as assembling and manipulating physical objects.

Another recommendation regarding the design of educational escape rooms is arranging puzzles in sequence in such a way that each puzzle unlocks the next one, forcing students to solve them in a specific order. This recommendation owes to three reasons. The first one is that arranging puzzles in sequence forces teams to work simultaneously on all puzzles and hence all the content is equally consumed by all team members. The second one is that linear paths require less guidance for students; thus, they often result in easier educational escape rooms without decreasing their learning effectiveness. The last reason why we recommend to follow a sequential path is that it facilitates the measurement of the progress and performance of all students, and hence the activity can be easily monitored. We also recommend designing the puzzles in such a way that they are of increasing difficulty. This way, it would be less likely for students to get stuck at the beginning of the activity, which can be very discouraging for them.

The results of this paper show that it is possible to successfully conduct educational escape rooms for teaching programming capable of allowing the simultaneous participation of many students. Therefore, we recommend that, whenever possible, educational escape rooms be designed to be conducted in a single session for all participants, thus allowing to significantly reduce the time invested by the course staff since it would not be necessary to conduct the activity in multiple time slots. Another advantage of running only one session is that this way participants cannot receive information from other students who have performed the escape room before them.

When conducting educational escape rooms for teaching programming, we propose to team up students in pairs instead of forming larger teams. This way, students can take advantage of the benefits of pair programming, which have been strongly evidenced in [32] and [33]. Another purpose for having students work in pairs is that it is more likely for them to shift leadership roles throughout the activity in comparison with larger teams, a benefit that has been also reported by Pan *et al.* [3].

Hint management during educational escape rooms is an essential factor for their success. However, as mentioned before, this is not a topic to which prior works have paid special attention. In the educational escape room reported in this study, an innovative hint approach was put into practice, which required students to get four out of five random questions right in a web-based quiz that covered the course materials in order to get a hint from the teachers (details about this approach are provided in section III-B). Based on our experience, we strongly believe that this hint approach was very appropriate. On the one hand, it forced students to review some of the course's theoretical content, complementing the practical skills that the escape room put to the test. On the other hand, it prevented students from continuously calling for help, since getting a hint required a significant effort on their part. During the course of the escape room, we observed that the cadence with which students asked for a hint was very moderate and that they only resorted to the hint application when they were truly stuck. Another advantage of the strategy we followed for giving hints is that the application used can be easily modified to include new questions or change existing ones, allowing its update for subsequent editions or even for different courses. Moreover, the criteria for issuing a hint can be adjusted with a view to modulate the difficulty of the escape room. Building web-based quiz applications, like the one we used, is relatively easy and can be done through existing tools such as RESCORM [41]. Although we are quite satisfied with the outcomes of the hint approach used in the educational escape room, we recognize that there is room for improvement. Students' feedback on the activity suggests that this hint approach was not sufficiently effective for some participants. Therefore, we recommend using our hint approach accompanied by additional measures such as giving free hints for lagging students or disclosing hints to all participants at specific time points. An even better approach would be to automate the process of issuing hints. In order to do this, it would be necessary to define all hints for each puzzle in advance and keep track of the hints already given to each team so as to present them with a new hint every time. In this regard, it could be quite useful to make the different hints automatically given to students for the same puzzle increasingly helpful. Another option to deliver hints to the students during an escape room is to use a hybrid approach, in which hints can be delivered automatically by a software system (such as the quiz application used in our experience) or by the teachers present in the activity when the automatic hints are not enough for effectively helping the students.

An important decision in the design of an educational escape room is how the activity is going to be evaluated. This is a concern that raises with gamification approaches in education [42]. One option is to offer the educational escape room as a non-graded activity. However, making the activity count for a grade could be beneficial in order to motivate the students to review the corresponding course materials in advance, which is a key factor in the success of educational escape room experiences. In this regard, it should be taken into account that educational escape rooms pose a greater challenge for the course staff when it comes to grading since the outcome of the activity is binary: whether a student escapes (i.e. solves all puzzles) or not. Therefore, if teachers intend to assign non-binary grades instead of providing a pass/fail mark, they must monitor the educational escape room activity in order to keep track of the students' performance, which requires to gather information such as how many and which puzzles each team has solved, the number of hints each team requested per puzzle, and the time points in which all these actions occurred. This kind of monitoring should be performed in an automatic way because otherwise, it would depend on the teachers' observations and thus it would be implausible for educational escape rooms targeting large groups. By gathering accurate information about an educational escape room activity, teachers can assign grades based not only on its final result (i.e. which teams solved all the puzzles) but also on the individual learning objectives met by each team and/or the achievement of specific milestones. Furthermore, teachers could adjust the grades depending on the number of hints requested by each team. Additional information that teachers could find useful for assessing the activity is how good students were at building teamwork, which role they played inside of their teams, and which was their individual contribution. Unfortunately, automatically monitoring this information seems currently unattainable, and thus it should be gathered manually through teacher observation which, as mentioned before, is not feasible for mass-attendance activities. Another concern related to the grading of educational escape rooms of which teachers should be aware, is that students generally do not have notions on how these innovative activities are evaluated since they usually have not had previous experiences. This can cause unease among students, especially for those accustomed to obtaining high scores. The continuous turmoil regarding grades can represent a major hindrance for student engagement [43]. Taking all these into account, teachers should carefully decide the grading scheme to be used in educational escape room activities and clearly explain said grading scheme to the students before the activity.

Finally, on the basis of the lessons learned from the experience reported in this paper, we propose a workflow for teachers to design and conduct educational escape rooms. The proposed workflow is comprised of the following nine phases:

1) Discuss and define how to incorporate the escape room into the course, its requirements and its general design. This task involves many decisions, including the duration, grading scheme and capacity of the activity. In order to accomplish this task, several factors should be taken into account, such as the course characteristics, the profile of the students, and the available personnel, equipment and facilities.
2) Identify the specific learning objectives of the course that the educational escape room should cover.
3) Decide what kind of puzzle would be more appropriate to address each learning objective identified in the previous phase and how many puzzles the educational escape room should have taking into account its duration.
4) Define an engaging narrative that is compatible with the course content covered.
5) Design and build the puzzles, clues, hints and the rest of the resources needed to conduct the escape room.
6) Test each puzzle individually.
7) Perform a simulation to test the whole educational escape room in a real setting.
8) Refine the educational escape room based on the simulation output.
9) When conducting the educational escape room with its intended audience, collect feedback in order to improve the activity for future editions.

The proffered workflow does not stray too far from the framework proposed in [44], although there are some differences. For instance, our workflow suggests to broadly define the puzzle types before the narrative, since their nature and the learning objective addressed in each one of them can be a constraining factor in the selection of the theme of the escape room. In fact, designing the puzzles and the narrative could also be done following an iterative process, in which the general storyline is gradually adapted to match the requirements of each puzzle. Our workflow also indicates additional aspects that should be taken into account in the initial design phase of the escape room such as the approach to incorporate the activity into the course (including the grading scheme) and the availability of personnel, equipment and facilities. Another noteworthy difference is that our workflow stresses the need for testing each of the puzzles individually, testing the whole educational escape room through a simulation in a real setting, and refining the activity based on the output of these tests. In fact, one of the most important lessons learned from this experience is this need for testing the escape room thoroughly, which has also been pointed out by other researchers such as [13], [14], and [23]. Detecting and fixing errors in the design of an educational escape room is key for its success since the presence of an error in a puzzle could have catastrophic consequences. For instance, it could create confusion given that students may think that it is part of the narrative (as evidenced by the results of our experience) and prevent students from progressing to the next puzzles, which could ruin the activity if teachers do not detect the error soon enough and think up a solution for the incident on the spur of the moment. In this regard, it is also worth pointing out that the high specificity of the learning materials in computer science courses poses an additional difficulty in finding volunteers for the testing session. For this reason, we also recommend collecting feedback from students after conducting an educational escape room with a view to making improvements for subsequent editions.

## VII. CONCLUSIONS

This paper reports the results of a case study in which an educational escape room was conducted in a programming course at a higher education institution. These results provide, for the first time, insights on the instructional effectiveness of using educational escape rooms for teaching programming. Based on these results, it can be suggested that appropriate use of educational escape rooms can have significant positive impacts on student engagement and learning in programming courses. These findings, which are consistent with those of [10]–[20], provide more evidence that educational escape rooms constitute a compelling way to increase student engagement.

This study also found that students preferred the conducted educational escape room over traditional computer lab sessions and that they perceived the learning outcomes somewhat higher in the former. Previous works have provided similar findings [14], [16], although this specific comparison was not addressed by any of them. Another novel and relevant finding of this study is that, despite the fact that female students showed less prior interest in games, they enjoyed the escape room as much as their male counterparts. Previous studies [45], [46] identified a gender bias in gaming, which resulted in specific games for each gender. Nonetheless, according to the evidence provided by this work, educational escape rooms seem to be attractive and effective for both genders equally, which is a highly valuable insight for the research and educational communities.

Little work has been done in order to address the challenges of designing and running educational escape rooms capable of allowing groups with numerous students to participate at the same time. Therefore, this work makes an important contribution to this growing research field by reporting a success case in which an escape room of this type was designed and run in a higher education setting.

Built on lessons learned from the design and execution of the reported educational escape room, this paper presents a set of recommendations for educators in order to help them create effective educational escape rooms for teaching programming, including a specific workflow to which to adhere when creating and carrying out a similar activity. Since there are no previous works on educational escape rooms that target programming courses, these recommendations are another unique and highly valuable contribution of this paper. Among the most important recommendations, it is worth highlighting the advisability of providing students with strong initial guidance, combining computer-based and physical puzzles, arranging puzzles in sequence (preferably with increasing difficulty), teaming up students in pairs instead of forming larger teams, and testing the whole escape room thoroughly. Regarding the provision of help during the activity, we recommend using a hint approach that requires students to answer questions on theoretical concepts accompanied by additional measures such as giving free hints for lagging students or disclosing hints to all participants at specific time points. Additional recommendations include performing the activity in a single session for all participants whenever possible, grading the activity in order to motivate students to review the course materials covered in advance as well as to clearly explain the grading scheme adopted to them, keeping track of the students' performance, and collecting feedback to improve future editions.

With the rise of distance learning through MOOCs and virtual learning environments, highly engaging activities like educational escape rooms could provide instructors of face-to-face courses with an added value capable of increasing students' motivation and getting them back in the classroom. Although the initial investment of time and effort on the part of the course staff to design and create educational escape rooms is, in principle, notably higher than that of other traditional hands-on learning activities such as computer lab sessions, their markedly and undeniable positive effect on student engagement as well as their ability to be reused in the following years makes it worthwhile. This capacity of escape rooms to be reused was previously noted by Gómez-Urquiza *et al.* [10] and Cain [14], who also remarked their positive effects on student motivation. Moreover, the fact that educational escape rooms can be designed to be of the same duration as regular class lectures or practical learning activities eases their incorporation into a course instructional design. In view of all these facts, it seems that there are no insurmountable barriers that prevent educational escape rooms to fit in a programming course curriculum.

This research throws up many questions in need of further investigation. For instance, a quantitative assessment of how educational escape rooms impact student academic performance on a certain topic is certainly needed in order to further understand the pedagogical utility of this novel teaching method. Further research is also needed to analyze how different approaches for issuing hints, puzzle organizations, levels of difficulty, or team sizes influence the instructional effectiveness of educational escape rooms. Another valuable direction for future work would also be to examine the benefits for teaching programming that may arise from using educational escape rooms that incorporate new technologies such as virtual and augmented reality [47], as well as novel resources such as virtual and remote laboratories [48], [49].

Finally, another interesting line of future work would be to provide solutions to automatically monitor educational escape rooms in order to keep track of the students' progress and performance. Of special interest would be solutions capable of capturing data about the students and their interactions during the course of escape rooms, and providing learning analytics to teachers in real time that they could use to drive interventions for enhancing the experiences. In this regard, we plan to develop an open source web-based platform capable of fully managing and monitoring educational escape rooms, keeping track of students' progress and performance with a high level of accuracy as well as generating learning analytics and intervention suggestions in real time. The objective of building this platform is to enable the creation of educational escape rooms with the ability to deliver hints automatically, control the flow of participants through the experience, and change the activity based upon their performance. According to [28], these are features that fourth generation educational escape rooms are expected to have.

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