Received February 10, 2021, accepted April 13, 2021, date of publication April 15, 2021, date of current version April 23, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3073601

Comparing Face-to-Face and Remote Educational Escape Rooms for Learning Programming

SONSOLES LÓPEZ-PERNAS[1], (Graduate Student Member, IEEE), ALDO GORDILLO[2], ENRIQUE BARRA[1], AND JUAN QUEMADA[1], (Life Member, IEEE)

[1]Departamento de Ingeniería de Sistemas Telemáticos, ETSI Telecomunicación, Universidad Politécnica de Madrid, 28040 Madrid, Spain
[2]Departamento de Sistemas Informáticos, ETSI Sistemas Informáticos, Universidad Politécnica de Madrid, 28031 Madrid, Spain

Corresponding author: Juan Quemada (juan.quemada@upm.es)

ABSTRACT Existing literature has provided strong evidence that educational escape rooms are engaging and effective learning activities when they are properly conducted in the classroom. However, no prior research has determined whether the positive effects of these novel educational activities on students' perceptions and learning persist when conducted remotely. This article performs, for the first time, a comparative study of the effectiveness of face-to-face and remote educational escape rooms. For this purpose, two versions of the same educational escape room were conducted: one in-class and one remotely. Both experiences were evaluated by means of three different instruments: (1) a pre-test and a post-test for measuring learning gains, (2) a questionnaire for assessing students' perceptions, and (3) a web platform for recording student interaction data during the activities. The results obtained suggest that, although remote educational escape rooms for learning programming can be as engaging as their face-to-face counterparts, their learning effectiveness is somewhat lower.

INDEX TERMS Computer science education, distance learning, educational escape rooms, educational technology, electronic learning, engineering education, technology enhanced learning.

I. INTRODUCTION

Escape rooms have become one of the most prominent leisure activities over the last few years [1]. Nicholson defined escape rooms 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'' [2]. Escape rooms appear to be one of the few occurrences in which a video game was turned into a real-life activity and not vice versa. The origin of escape rooms is commonly attributed to a genre of video games called ''escape the room'' [2] in which players have to interact with a virtual room by clicking on different objects in order to escape. However, the way in which the leap from the virtual world to the physical world took place is a little unclear. The earliest documented activity that can be considered an actual escape room was designed by the publishing company SCRAP [3] and released under the name of ''Real Escape Game''. It was set up in Kyoto, Japan in 2007 as a single room game for teams of 5 or 6 players. This new phenomenon rapidly spread through Asia and did not take long to reach Europe (especially Hungary), and later Australia and North America. As of December 2020, the World of Escapes directory [4], one of the biggest escape room public databases, listed more than 12,000 different escape rooms spread over dozens of countries throughout the world.

It was not until 2017 that escape rooms ventured into the education sector and drew the attention of academics. Based on the growing market and the documented engagement levels that leisure escape rooms generated within diverse types of players, the authors of [5] set out to test the appeal and educational value of these forms of games within a higher education setting and developed a prototype educational escape room for a university staff training event with the aim of showcasing the potential of these activities to other educators. That same year, escape room experiences involving students were reported in the literature for the first time [6]–[10]. Since then, escape rooms have been used in a wide range of educational settings and their potential as learning activities has inevitably

The associate editor coordinating the review of this manuscript and approving it for publication was John Mitchell.

attracted the attention of many researchers [11], as evidenced by the exponential growth that this field of research has had in recent years. These escape rooms, known as ''educational escape rooms'', 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. Prior works have provided firm experimental evidence that educational escape rooms can produce positive impacts on student engagement [6], [9], [12]–[36] and learning [9], [24], [29], [30], [33], [34]. This potential, coupled with the fact that they can be applied in a wide variety of knowledge areas, has made them an increasingly popular learning activity at all stages of education.

Educational escape rooms combine some of the key principles of game design with sound learning approaches. Among the main educational theories behind educational escape rooms is active learning, which can be defined as ''any instructional method that engages students in the learning process'' [37]. One of the most representative characteristics of active learning is that it requires students to do meaningful learning activities and think about what they are doing [38]. Educational escape rooms are a perfect example of active learning since students need to interact with a wide range of elements and figure out how to solve the different escape room puzzles. By facing these puzzles, students put their knowledge of the course materials to the test and develop their skills in an active way. Specifically, by participating in an educational escape room, students strengthen their problem-solving skills, since the puzzles require players to identify and solve problems through observation and logical thinking [30]. Stemming from active learning, a related educational theory that is a cornerstone of educational escape rooms is collaborative learning. Collaborative learning can be defined as ''any instructional method in which students work together in small groups toward a common goal'' [37]. Educational escape rooms are a rather favorable atmosphere for collaborative learning, as they usually present an objective on which students need to work together, requiring them to make adequate use of their time, shared resources and individual skills in order to succeed in the activity.

One of the reasons why educational escape rooms have been so successful is because they are capable of immersing players in what is known as a state of ''flow'' [39]. A state of ''flow'' is achieved when players are engaged in tasks that are neither too easy nor too difficult, but rather in a middle ground in which they can succeed but only with some struggle. In educational games, just like in educational escape rooms, achieving a state of ''flow'' while playing is usually related to cognitive engagement, which takes place when the learner engages with the learning mechanic [40]. If cognitive engagement is not achieved, the game will likely not be effective in helping learners achieve the learning goals. In the case of educational escape rooms, cognitive engagement is achieved through challenging puzzles that are capable of captivating students. In games, engagement is what makes players keep playing over long periods of time. However, the actual type of engagement will differ by game and within a game, as different game features elicit different types of engagement in different contexts and for different players [40]. For instance, social features such as collaborative play support what is known as sociocultural engagement, which deals with social interactions embedded within a cultural context. In fact, interaction in games does not only occur in the form of feedback and rewards but it also takes place among the game players, bringing to light the inherently social aspect of games, which promotes the formation of social groupings [41]. In educational escape rooms, this type of engagement stems mainly from interactions among students of the same team towards the achievement of their common goal. Related to this is affective engagement, which appeals to emotion processing and regulation [40]. Game characters and narrative, for instance, have the ability to engage the learner emotionally. As a matter of fact, there exists a difference of opinion about whether these characteristics are at the essence of what makes a game, or if they are just frills around it [41]. Clearly, in educational escape rooms, narrative articulates the whole experience since it gives a purpose for the tasks performed in the activity and provides the ''excuse'' for the limited time to carry them out. Lastly, behavioral engagement involves gestures, embodied actions, and movement [40]. Physical activity is commonly a centerpiece of educational escape rooms, playing a crucial role in achieving behavioral engagement.

Despite the fact that behavioral engagement seems to be one of the reasons why educational escape rooms are so attractive, due to its ability for achieving immersion, in order to effectively deliver these novel activities in online distance learning settings, it is necessary to seek alternative ways for conducting them that do not heavily rely on physical elements or bodily actions. Naturally, the first option that comes to mind is to recapture the origins of primeval escape rooms and reinstate ''escape the room'' video games, offering educational escape rooms as digital games that can be consumed remotely using a computer or some other electronic device. Sociocultural engagement may also be affected by this delivery format, since collaboration between members can be challenging to perform remotely as well. Although a few virtual educational escape rooms can be found in the literature [26], [29]–[31], [34], [35], [42], only four works [26], [31], [34], [42], to the knowledge of the authors, reported on the use of remote educational escape rooms. However, said works did not compare the effectiveness of face-to-face and remote educational escape rooms. Indeed, only in one of them the learning gains of the activity were measured in an objective way [34]. In sum, although in-class educational escape rooms have proven to bring multiple benefits in terms of student engagement and learning effectiveness, evidence that the same benefits are achieved in remote educational escape rooms is scarce. Specifically, there is a paucity of research examining whether these benefits persist when a face-to-face educational escape room is transformed into a remote one.

To fill the gap in the existing literature, the goal of this article is to determine whether an educational escape room conducted remotely can yield the same benefits as the same escape room carried out face-to-face in terms of students' perceptions and learning effectiveness, and to examine whether students' performance during the activity (success rate, number of puzzles solved and number of hints requested) differs between in-class and remote educational escape rooms. With this aim, two versions of the same educational escape room for learning programming were carried out. First, an educational escape room was conducted face-to-face in a computer science course. Then, this educational escape room was adapted and, one year after the first experience, this new version was conducted remotely in the next offering of the same computer science course. The remote educational escape room (i.e. the remote version of the escape room) was the result of transforming the in-class escape room to a fully-digital format so it could be conducted remotely. Both escape room experiences were evaluated with the same three instruments: (1) a pre-test and a post-test to measure students' increase in knowledge, (2) a questionnaire to collect their perceptions, and (3) a web platform for automatically recording data on students' interactions during the activities in order to obtain information on the students' performance in the educational escape rooms. The results obtained from both evaluations are discussed and compared. The in-class educational escape room was previously examined in [33]. The present article compares the in-class escape room and its remote counterpart in order to determine whether in-class and remote educational escape rooms have the same effects on students.

The rest of the article is organized as follows. The next section provides an overview of the existing literature on educational escape rooms. Section III describes the educational escape rooms carried out. Section IV explains how the educational escape room experiences were evaluated and compared. Section V shows and discusses the results obtained from both evaluations, comparing them to each other. Lastly, Section VI finishes with the conclusions of the article and an outline of future work.

II. RELATED WORK

Different researchers have reported on using educational escape rooms in a wide variety of fields such as nursing [13], [14], [17], medicine [8], [15], [18], [19], [22], physiotherapy [6], pharmacy [9], [12], [16], [23]–[25], [43], physics [10], chemistry [20], [21], [26], [27], [31], [42], biology [28], [29], cryptography [44], mathematics [35], [36], programming, [32], [33], software modeling [34] and computer networks [7]. These studies have provided firm experimental evidence that educational escape rooms can produce positive impacts on student engagement [6], [9], [12]–[36] and learning [9], [24], [29], [30], [33], [34].

In the majority of existing works on educational escape rooms, these activities were conducted as in-class experiences in which students were grouped in teams and given a limited time to complete a series of puzzles and accomplish the goal of the escape room, which could be escaping from an actual room or something else like developing a cure, defusing an explosive device, etc. More often than not, the puzzles combined field-specific knowledge and skills with generic puzzle mechanics found in ludic escape rooms such as opening combination locks, finding keys, assembling objects, etc [2]. A few works have transcended the physical barrier and developed purely virtual or digital educational escape rooms [26], [29]–[31], [34], [35], [42]. In spite of the fact that the educational escape rooms reported in said works were completely virtual, in more than half of them ([29]–[31], [35]) the activities were hosted as face-to-face events, although in [31] the possibility of playing remotely and individually as a homework assignment was also given to students. Thus, only three works [26], [34], [42] reported on remote educational escape rooms conducted as synchronous events in which several students participated simultaneously.

A single work [26], to the knowledge of the authors, established a comparison between a face-to-face and a remote educational escape room, although this comparison only addressed students' perceptions and did not use statistical methods to draw conclusions from the collected data. The authors of [26] had previously conducted a physical escape room for learning chemistry in higher education, but due to the rise of the COVID-19 pandemic, they were forced to develop a fully virtual and remote version which students could complete individually or as a group through videoconferencing platforms. The results of the questionnaire administered to students after participating in either the face-to-face or remote educational escape room showed that the in-class educational escape room obtained better results in terms of engagement and motivation. However, this study did not report statistical significance for the differences and did not measure the actual effect of either educational escape room on students' learning. Thus, there is a paucity of research examining how the learning effectiveness of educational escape rooms varies from in-class to distance learning settings and more solid research is needed to draw precise conclusions on the difference in students' perceptions between the two settings.

III. DESCRIPTION OF THE EDUCATIONAL ESCAPE ROOM EXPERIENCES

A. CONTEXT

The educational escape rooms compared in this study were conducted in two subsequent academic years in a programming course that is part of the Bachelor's Degree in Telecommunications Engineering from Universidad Politécnica de Madrid (UPM). This programming course is a third-year course that accounts for 6 ECTS (European Credit Transfer System) credits, equivalent to 150–180 hours of student work. In this course, students learn the basics of web development, including HTML, CSS and JavaScript, and more advanced technologies such as node.js, express, and SQL. In both years,

the educational escape room was offered to all the students in the course as an extra-credit activity that lasted two hours.

The aim of conducting the educational escape rooms was to reinforce the most important concepts covered throughout the programming course in a motivating and engaging way. In view of the successful results obtained in the in-class educational escape room conducted in this course, which were reported in [33], the faculty staff decided to repeat the same experience. Thus, the exact same educational escape room was initially planned to be carried out face-to-face in a computer laboratory again. However, when the COVID-19 pandemic stroke, conducting the educational escape room as an in-class activity was no longer a possibility. Instead of refraining from conducting the escape room, the course instructors set out to run it remotely, performing the necessary changes on the escape room so it could be conducted in an online distance learning setting.

B. DESIGN

Below is a summary of the design characteristics of the two escape rooms compared in this study, indicating the changes that had to be performed in order to adapt the face-to-face version to the distance setting. In this regard, it should be remarked that the minimum number of changes were applied for performing this adaptation and that most design characteristics remained unchanged.

- **Team size**: Students were grouped in self-selected pairs, allowing them to take advantage of working as a team and enjoy the benefits of pair programming [45], [46].
- **Duration**: Students had two hours for completing the educational escape room.
- **Puzzle structure**: The puzzles of the escape rooms were arranged in a sequence, i.e, each puzzle unlocked the next one.
- **Puzzle types**: The in-class escape room combined computer-based and physical puzzles whereas, in the remote educational escape room, only digital puzzles were used. Section III-C provides further details about the changes that had to be made to convert the physical puzzles into digital ones.
- **Hint strategy**: In order to allow students to get help when they got stuck during the escape room, they were allowed to request hints at any time through a web application. Each time a team requested a hint by means of this application, a quiz with 5 questions about the course materials randomly chosen from a pool was presented. In order to obtain the hint, the team had to answer at least 4 out of the 5 questions correctly.
- **Large-enrollment**: Both educational escape rooms were designed in such a way that they enabled the participation of a large number of students at the same time. In the in-class educational escape room, all the physical elements of the puzzles were paper-based, so they could be easily replicated in an inexpensive way. The main limitation was the availability of a large enough space to fit all students at the same time, requiring instructors to book a computer lab in advance. In the remote educational escape room, no dedicated space was required and, since all the puzzles were digital, they could be replicated as many times as required at no cost. Further details on how the escape rooms were conducted can be found in Section III-D.

C. NARRATIVE AND PUZZLES

The narrative was exactly the same in both the in-class and remote versions of the escape room: students are presented with an emergency situation in which an accident has taken place at a molecular biology center, releasing a deathly virus that infected two employees of the center, including the researcher in charge of developing the vaccine, who passed away as a consequence of the infection. In order to help the other employee recover, and before anyone else becomes infected, it is necessary to prepare a vaccination shot. However, the only one who knew how to retrieve the genetic code of the vaccine was the deceased. Fortunately, he had developed a web application for managing his clinical trials, which could be used to obtain the genetic code necessary for producing the vaccine. Although the database containing the trials survived the accident, the trial web application did not. A preliminary, unfinished version of this web application was rescued from an old back-up of the deceased's hard drive, along with some of his personal files. The web application was developed using HTML, CSS, JavaScript, node.js, express, and SQL (the technologies taught in the course). A government agent resorts to the students, as the world's greatest experts in said technologies, requesting their help to rebuild the trial web application and gain access to the genetic code of the vaccine. There are only two hours left (the duration of the escape room activity) to perform this task and retrieve the genetic code of the vaccine before it is too late for the infected employee.

In both escape rooms, puzzles combined field-specific tasks (such as downloading, installing and running a web application, writing HTML code, performing SQL queries, etc.) with classic puzzle mechanics that are usually found in ludic escape rooms (searching for hidden objects, symbol substitution, etc.). The remaining of this section is a summary of the puzzles of both educational escape rooms (shown in Fig. 1), including the changes that had to be made to the in-class escape room to adapt the activity to the remote scenario.

The first task that students had to accomplish was downloading the researcher's hard-drive back-up (which contained all his files and the trial web application) from GitHub, where the government agent had previously uploaded it. Students had to install the dependencies, start the application and log in, for which they needed to figure out the credentials by inspecting the personal files of the researcher located in the hard drive. When looking through the hard drive files, they could see that there were several symbols hiding in different locations, each one corresponding to a different chemical

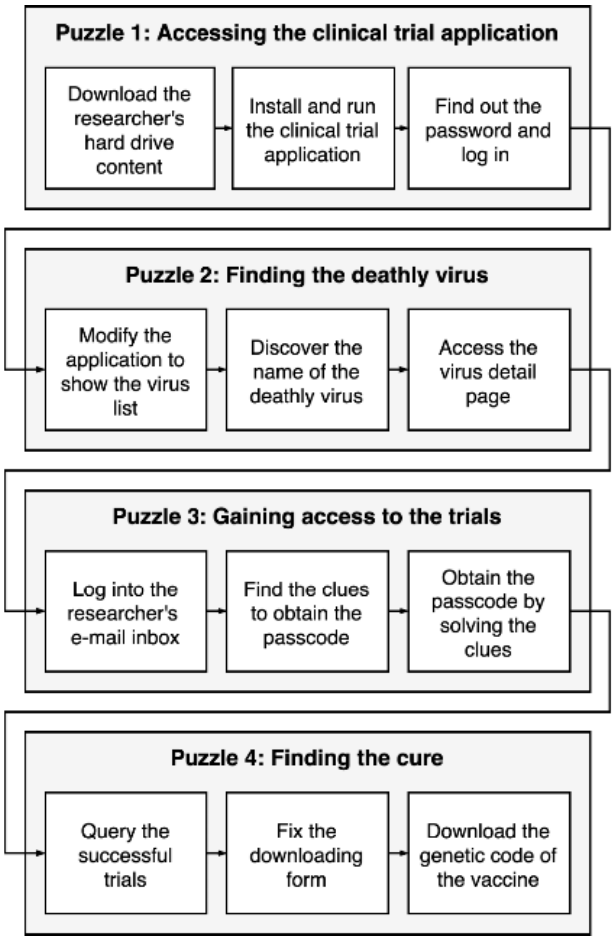

FIGURE 1. Flow chart of the escape room puzzles.

element, but at that point they had no clue of what to do with them. Once they accessed the application, students had to display the complete list of viruses available in the database in the web interface by writing the corresponding EJS code. Then, they had to figure out the name of the deathly virus by reading a draft paper available in the hard drive in order to gain access to its trials. However, students encountered that the trials of that specific virus were protected by a security access code. Students needed to gain access to the researcher's e-mail inbox to obtain the access code that he had sent to his colleagues via email.

At this point, the remote escape room diverged from the in-class one. In the latter, one of the emails pointed students to a physical locker at students' school where there was an envelope in which the researcher had enclosed two paper sheets with the clues needed to figure out the access code. Besides walking to the locker, these clues required students to perform more actions that involved physical objects, such as putting a paper through back-lighting, figuring out the output of an excerpt of code that was printed out, and assembling a QR code from different spare pieces in order to scan it, ultimately leading to an online interactive periodic table in which they needed to click on five chemical elements in the right order to obtain the access code. They had to figure out which elements they needed to press by finding the corresponding symbols hidden in the hard drive files (the ones mentioned earlier) and in the envelope clues, and guess the right order by interpreting the code excerpt.

Since the physical tasks were no longer feasible in the remote escape room (without previously mailing the envelope content to students or having them print it out), several changes were made to digitalize them. First, instead of hiding the clues in the locker, the programming code excerpt was included as an email attachment in an email in the researcher's inbox (instead of disclosing the locker number like in the in-class edition), and the link to the interactive periodic table was included in the body of the same email. The symbol that was discovered by putting the paper through back-lighting in the in-class escape room was now hidden inside the content of another seemingly useless email. The remaining symbol included in the paper sheets was now concealed in a page of the web application. Thus, students could find the same chemical elements as in the in-class escape room, figure out the right order to click on them in the interactive periodic table, and unveil the access code. That was the only part of the escape room puzzles that had to be altered for the remote fully-digital escape room.

Thereafter, students had to enter the access code in the trial application to access the clinical trials of the virus. Then, they needed to perform an SQL query to filter the trials in order to find only those that were successful. Once they accessed the only successful trial, they had to fix an HTML form that allowed them to download the genetic code of the vaccine and succeed at the escape room. More details about the puzzles that students needed to solve in order to complete the escape room can be found in [33], including the puzzle mechanics and learning objectives addressed in each puzzle.

D. EXECUTION

In order to carry out both educational escape rooms, the faculty staff relied on the Escapp platform [47]. Escapp is a web platform that aims to help instructors throughout the whole process of conducting an educational escape room both face-to-face and remotely, including student registration, team formation, control of the execution of the activity (management of multimedia resources, narrative events, and gamification elements), progress monitoring, hint management, and grading.

In the in-class educational escape room, which was the first one to be conducted, the instructors had to create a profile for the escape room in Escapp providing the basic information of the activity: its name, the course to which it belongs, the duration of the activity, the maximum team size allowed, and the date of celebration. Then, the instructors had to manually enter the different puzzles and their solutions in the right order, along with a set of hints for each puzzle. In addition, the pool of questions for the quiz-based hint approach was provided along with the settings needed to display five questions per quiz and to require students to get at least four answers right in order to get a hint. Then,

a set of instructions for students to read before the escape room was provided by the teachers, including the rules of the activity and additional useful information to take into account at different stages of the escape room. Moreover, the interface that students would see during the escape room (known as team interface) was customized by including a link to the Github repository containing the hard drive back-up and another link to a police report containing useful information for students to figure out where to begin. Moreover, an initial video explaining the narrative and goal of the escape room was included in the class interface (an interface for screening during the escape room for the whole class to see), as well as a countdown. Lastly, the instructors set up the grading scheme for the escape room, in which the totality of the grade was based merely on attendance, which was taken manually by roll call. Once the escape room profile was completed, the instructors shared the link to join the escape room with the students. Students enrolled in the activity by creating a new team or joining an existing one and could read the activity instructions before participating. When the time came to conduct the escape room, students arrived at the computer laboratory and occupied one computer per team. Once instructors made sure that everyone enrolled was present and ready to start, they initiated the escape room session using Escapp, starting the countdown and allowing students to access the escape room content for the first time through the team interface in Escapp. First, the introductory video was played by screening the class interface. After watching the video, students had to figure out on their own how to proceed by inspecting the rest of the escape room content included by the teachers on the team interface (the links to the escape room resources). Students had to work with their partner to progress through the escape room. Regarding the role of the teachers during the activity, they monitored students' actions through the learning analytics dashboard provided by Escapp and also by walking around the laboratory. Thanks to the dashboard, the teachers could detect lagging teams and verify if they were having trouble. In case a team was having trouble, the instructors would approach them and give the students some pointers to help them advance or encourage them to request a hint. Once the escape room was over, the data gathered during the activity was used to review students' performance. Lastly, Escapp was used to generate the activity's grade sheet, which was directly imported by the teachers in the course LMS.

Each one of the digital puzzles in the educational escape rooms was connected to the Escapp platform through its API. This means that every time that students made an attempt to solve a puzzle, Escapp's API was used to verify whether it was the correct solution, updating the team's progress accordingly. Moreover, since all the digital puzzles were web-based, the Escapp client library was used to facilitate the use of the API, taking care of authenticating students against Escapp and submitting each attempt to solve a puzzle. Through the team interface, team members could request a hint whenever they got stuck by using the quiz-based approach mentioned earlier. Since Escapp keeps track of teams' progress, it was ensured that the hints that were automatically handed out to students were useful for the part of the escape room they were working on.

With regard to the remote educational escape room, conducted the subsequent year, since the design characteristics of the escape room remained the same, the instructors were able to clone its profile in Escapp. Only a few modifications had to be made. First, all the information that was included in the screened class interface (initial video and countdown) was transferred to the team interface, so students could see it on their screens while participating. In addition, instructors chose to take attendance automatically for each student, i.e., students were considered to be present only if they logged in to Escapp and accessed the escape room while it was active. Moreover, a link to a video conference room was provisioned by the instructors, which students had to join before the escape room started, and that they could use in case they experienced technical problems during the escape room. The process of enrolling in the escape room was the same as in the in-class escape room. When the time came to conduct the escape room, students had to join the video conference room. The faculty staff supervising the activity waited until all the students that were enrolled joined the video conference in order to start the escape room. Just like in the in-class escape room, once the activity officially started, students could access its content through the team interface. In this case, the introductory video was played automatically on start up. Students were asked to remain in the video conference room, which was used by the teachers to help lagging teams in a similar way to the face-to-face escape room when they were identified through the learning analytics dashboard, as well as to cheer students by congratulating the first team to solve a puzzle, the first one to complete the escape room, etc. Furthermore, students in the same team could talk and share their screen via their preferred videoconferencing platform to enable real-time collaboration and take advantage of the benefits of pair-programming even from a distance. In this experience, in which both team members participated from separate computers, the Escapp client library allowed to synchronize the escape room state between them, so they could both be at the same point at all times, easing real-time collaboration. Moreover, this library was also used for showing relevant events to students in real-time during the escape room, such as warnings of the time remaining and notifications each time a new puzzle was solved or a new hint was obtained by anyone in the same team. For the rest, there were no further significant changes between the two experiences.

IV. EVALUATION METHODOLOGY

This section presents the methodology used to compare the learning effectiveness, students' perceptions and students' performance between the two educational escape rooms examined in this article: one conducted in-class and one conducted remotely. Three instruments were used to gather data from both experiences: (1) a pre-test and a post-test to

measure students' increase in knowledge, (2) a questionnaire to collect their perceptions, and (3) the Escapp platform for automatically recording data on students' interactions during the activity in order to obtain information on the students' performance in the educational escape rooms.

A. EVALUATION OF LEARNING EFFECTIVENESS

In order to accurately measure the learning effectiveness of the educational escape rooms carried out, a pre-test was conducted right before the start of each educational escape room, and a post-test was conducted right afterward. Both tests contained the exact same ten multiple-choice questions on the course materials. The correct answers were not revealed to students until after completing the post-test (i.e. no feedback was provided during the pre-test preventing students from memorizing the answers). The knowledge required to solve the questions on both tests was akin to the knowledge that students needed to have in order to solve the puzzles of the educational escape rooms. The ten multiple-choice questions in the pre- and post-test assessed the entirety of the learning objectives addressed in the educational escape rooms. The time limit for solving each test was 10 minutes. Answering the 10 questions correctly required students not only to remember information, but also to clearly understand the main concepts covered in the activity, to analyze programming code fragments, and to know how to apply the acquired knowledge to solve specific programming problems. Therefore, the pre- and post- test allowed measuring not only recall but also knowledge understanding and application. Although the questions of the pre- and post-test and the ones presented by the hint application were related to the same set of learning objectives, no question from the pre- and post-test was included in the hint application (i.e. the questions of the pre- and post-test were different from the ones presented by the hint application). In the pre- and post-test, students were awarded 1 point for each question they answered right and were subtracted $1/(N-1)$ points for each question they answered wrong, N being the number of options in each multiple-choice question. They were allowed to leave answers blank with no penalty. The maximum score achievable by students was 10 and the minimum score was 0. This approach was aimed at preventing students from completing the questionnaires randomly. The pre-test and post-test results did not count towards students' final grades in order to avoid cheating and unexpected behaviors such as the one reported by [23], in which the pre-test accounted for a much more significant percentage of the grade than the post-test did, resulting in students putting more effort into the former. The difference in scores between the post-test and the pre-test was assessed by means of a paired-samples t-test after verifying that the data followed a normal distribution using Shapiro-Wilk's test. The effect size of this difference was measured using Cohen's d [48]. When using Cohen's d, a value of 0.2 indicates a small effect size; a value of 0.5, a medium one, and a value over 0.8, a large one. Moreover, the learning gains of each student were calculated by subtracting the pre-test score from the post-test one.

B. EVALUATION OF STUDENTS' PERCEPTIONS

Students' perceptions on each educational escape room were collected through a questionnaire that was conducted immediately after the termination of each post-test. This questionnaire included some initial demographic questions, a set of closed-ended questions addressing students' general opinion and acceptance of the activity, and a list of statements with which they needed to agree or disagree using a 5-point Likert scale. These questions were aimed at assessing students' perceived learning effectiveness and attitudes towards the use of the educational escape room as a learning activity, as well as students' thoughts on the design (difficulty, puzzles, duration, hint approach employed) and organization of the escape room, the team dynamics, the immersion of the experience, whether students preferred the escape room over a regular computer lab session, and whether they would have preferred to participate face-to-face, in the case of the remote escape room. At the end of the questionnaire, there was a space in which students could leave suggestions, complaints, and other comments. The questionnaire was validated by two faculty members who play-tested the educational escape room. The relationships of the different dimensions of the questionnaire with one another and with the learning gains were examined through Spearman's correlation analysis.

C. EVALUATION OF STUDENTS' PERFORMANCE IN THE ESCAPE ROOM

The Escapp platform was used in order to automatically record data on relevant student interactions during the course of both educational escape rooms. Specifically, the following data were collected: the students who made up each team, the puzzles solved by each team and the hints requested and received by each team. These data allowed to retrieve fine-grained information on students' performance during the educational escape room, rather than just a boolean outcome (whether they successfully completed the activity or not). Then, based on these data, relationships among this performance and students' learning effectiveness as well as students' attitudes were analyzed through Spearman's correlation analysis.

D. COMPARATIVE ANALYSIS

Furthermore, in order to compare the learning gains between both educational escape rooms, an independent samples t-test was used. The effect size of this difference was assessed through Cohen's d. In the reported results, a positive value for Cohen's d indicates that the learning gains were greater in the in-class educational escape room and a negative value indicates otherwise. The difference in the Likert-like items of the questionnaire and performance results was analyzed through the Mann-Whitney U-test. The effect size between responses of both escape rooms was calculated using Cliff's δ. A value of $|\delta|$ lesser than 0.147 is considered negligible, a value

between 0.147 and 0.33 is considered small, a value between 0.33 and 0.474 is considered medium, and a value greater than or equal to 0.474 is considered large [49]. Moreover, in the reported results, a positive value of δ for a questionnaire item indicates that the variable measured by the item was rated higher for the in-class educational escape room, whereas a negative value indicates the opposite. Lastly, the difference between the Yes/No questions in the questionnaire was assessed through Pearson's chi-squared test. The effect size of this difference was assessed through the ϕ effect size. A value of ϕ of 0.1 is considered a small effect, 0.3 a medium effect and 0.5 or more a large effect [48]. It is worth mentioning that a level of significance of 0.05 was set for all statistical tests performed in this work.

V. RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the sample of this study. All the participants were students of subsequent offerings of the same course arranged in pairs. All of them completed the pre-test, the post-test and the questionnaire individually. As can be seen, the sample characteristics are very similar in both groups in terms of age and gender ratio.

TABLE 1. Sample characterization.

	In-class			Remote		
Number of participants	28			104		
Number of teams	14			52		
Gender	**Male**	**Female**	**Other**	**Male**	**Female**	**Other**
	24	4	0	82	20	2
Age	**M**	**SD**	**Range**	**M**	**SD**	**Range**
	21.1	1.2	20-24	20.9	1.1	20-26

A. LEARNING EFFECTIVENESS

Table 2 shows the results of the pre-test and the post-test conducted in both educational escape rooms, including, for each test, the mean (M), median (MED), and standard deviation (SD).

In the in-class escape room, the mean score for the pre-test was 3.3 (MED = 2.8, SD = 1.6) on a scale of 0 to 10, whereas the average score for the post-test was 5.4 (MED = 5.8, SD = 2.3). The mean increase in scores (i.e., learning gains) was 2.1 (MED = 1.3, SD = 2.6). In the remote educational escape room, the mean score for the pre-test was 2.9 (MED = 2.8, SD = 2.0) on a scale of 0 to 10, whereas the mean score for the post-test was 3.9 (MED = 3.7, SD = 1.9). The learning gains were 1.1 (MED = 1.3, SD = 2.1).

In both experiences, the difference in scores between the post-test and the pre-test was found to be statistically significant when a two-tailed paired-samples t-test was performed, showing that students experienced a statistically significant increase in knowledge as a result of participating in either activity. The value obtained for Cohen's d was 0.7 for the in-class escape room, representing a medium to large effect size, and 0.5 for the remote escape room, representing a medium effect size. Thus, on the basis of our findings, it can be stated that both educational escape rooms increased students' knowledge of the course materials.

In the case of the in-class educational escape room, this finding is consistent with those of prior works that have shown evidence of the increase in students' knowledge of in-class educational escape rooms in other fields, such as pharmacy [9], [24] and science [29]. The authors of [24] found a difference in medians between the post-test and the pre-test scores of 33/100, which is very similar to the one found in this work for the face-to-face escape room (3.0/10). In [9], the difference in means between the post-test and the pre-test scores was 25/100, again close to the one reported in this work for the face-to-face escape room (2.1/10). The authors of [29] found lower learning gains, with a difference in means of 5.9/100. Nevertheless, not all previous works examining face-to-face educational escape rooms found positive learning gains [23], [30]. The authors of [23] blamed this on the fact that the pre-test accounted for a much more significant percentage of the grade than the post-test did, resulting in students putting more effort into the former. The authors of [30] argued that the post-test failed to assess some of the high-level thinking skills that students practiced in the educational escape room. However, although the scores of the post-test were lower than in the pre-test, the students who participated in the educational escape room outperformed those who received traditional instruction and showed improvements in problem-solving. Regarding remote educational escape rooms, the results obtained in the present study are in consensus with those of the only existing work addressing this aspect [34]. Said work also examined the use of a remote educational escape room in the field of computer science and reported an effect size of the difference between post-test and pre-test scores of 0.53, which is very similar to the one obtained in the present study for the remote educational escape room. Therefore, given the limited evidence published on the learning effectiveness of educational escape rooms, which is scarce and non-conclusive in face-to-face settings and almost non-existing in remote ones, the findings of the present study significantly contribute to the better understanding of this novel educational activities and further encourage instructors to adopt them.

A two-tailed independent samples t-test was performed to discern whether there was a significant difference between the learning gains of the two experiences. The results show that the difference in learning gains had a small to medium effect size (Cohen's d = 0.4), suggesting that the in-class educational escape room resulted in a larger increase in knowledge. This effect size was found to be statistically significant at the significance level of 0.1, although not at the significance level of 0.05. By examining the confidence intervals, we are 95% confident that the effect size of the difference between the learning gains produced by the face-to-face educational escape room and those produced by the remote educational escape room is between 0.31 and 0.49, i.e., a small to medium effect size. Since no comparison in terms of learning gains has been established before between face-to-face educational escape rooms and remote educational escape rooms, the findings reported in the present work

TABLE 2. Results of the pre-test and the post-test.

	Pre-test (0-10)			Post-test (0-10)			Learning gains			Cohen's d effect size	p-value (2-tailed) Paired samples t-test	Cohen's d effect size	p-value (2-tailed) Independent samples t-test
	M	MED	SD	M	MED	SD	M	MED	SD				
In-class educational escape room	3.3	2.8	1.6	5.4	5.8	2.3	2.1	1.3	2.6	0.7	**<0.001**	0.4	0.07
Remote educational escape room	2.9	2.8	2.0	3.9	3.7	1.9	1.1	1.3	2.1	0.5	**<0.001**		

constitute an unprecedented and valuable contribution to this growing field.

Moreover, no significant difference was found between the increase in knowledge achieved by men and women in either escape room when an independent samples t-test was performed on the learning gains produced by each one of them. This fact shows that both face-to-face and remote educational escape rooms can be effective learning activities for all students regardless of their gender, which is a finding consistent with those reported in previous research, both for face-to-face [32] and remote [34] educational escape rooms. However, this finding should be treated with caution due to the small number of female students in the sample.

B. STUDENTS' PERCEPTIONS

Table 3 shows the results of the student questionnaire conducted after each educational escape room including, for each question, the mean (M), the median (MED), and the standard deviation (SD). In order to compare students' answers between both escape rooms, a two-tailed Mann-Whitney U-test was performed for each questionnaire item. The p-value obtained for this test is included in each item of the table. In addition, the ϕ value and p-value of the Pearson's chi-squared test performed for the two binary items (Yes/No questions) at the end of the questionnaire have also been included in the table. The p-values of those items in which a significant difference have been found has been highlighted on the table for the reader's convenience.

The results of both questionnaires conducted in this study show that students had a positive overall opinion of both educational escape rooms (in-class: $M = 4.6$, $MED = 5.0$, $SD = 0.6$; remote: $M = 4.3$, $MED = 4.0$, $SD = 0.8$), although the overall opinion was better for those students who participated in the face-to-face escape room. This difference, albeit small in size (Cliff's $\delta = 0.26$), was found to be statistically significant, indicating that the opinion of the students who participated in the face-to-face educational escape room was significantly better than that of the students who participated in the remote one. Despite this small difference in general opinion, both escape rooms scored very high in terms of student acceptance, as evidenced by the fact that practically all participants said that they would recommend the activity to other students and that they would like similar activities to be carried out in other courses. Moreover, students' overall opinions on the escape rooms are within the same range as those reported in prior works, both in face-to-face [14], [18]–[20], [22], [29], [32] and remote [31], [34] educational escape rooms, suggesting that students are in general very open to these novel learning activities.

The students thought that participating in the escape room was a fun experience both in the case of the in-class escape room ($M = 4.4$, $MED = 4.5$, $SD = 0.6$) and the remote one ($M = 4.3$, $MED = 4.0$, $SD = 0.9$). The satisfactory outcomes obtained for this item of the questionnaire provide further proof that educational escape rooms can be highly engaging activities when used in programming courses, as anticipated by prior studies in face-to-face [6], [9], [12]–[30], [32], [35], [36] and remote settings [26], [31], [34]. Furthermore, a negligible non-statistically significant effect size was found on this item of the questionnaire for the difference between both educational escape rooms. Hence, there is no reason to believe that students' level of amusement was significantly greater in one experience than in the other one. Contradictory findings were reported by [26], who found that, on average, students enjoyed the remote educational escape room to a lower extent than in its face-to-face version. However, the authors of said work did not report the statistical significance of this difference, preventing any statistically reliable conclusion from being drawn about the variation between the two experiences.

Questionnaire respondents also thought the escape room was an immersive experience (in-class: $M = 4.3$, $MED = 4.0$, $SD = 0.7$; remote: $M = 4.2$, $MED = 4.0$, $SD = 0.8$), and once again a negligible non-statistically significant effect size was found among the two activities. This finding indicates that students were immersed in the game to the same extent regardless of whether the escape room was conducted face-to-face or remotely. Moreover, participants of the remote educational escape room liked that the escape room puzzles were digital ($M = 4.4$, $MED = 4.0$, $SD = 0.7$), which is consistent with the findings of [31], [34]. However, participants of the in-class escape room had the same opinion when asked whether they liked that the escape room combined physical and digital puzzles ($M = 4.4$, $MED = 4.0$, $SD = 0.7$). These results suggest that the format of the puzzles on its own does not greatly influence students' perceptions of the activity. In fact, students who participated in the remote escape room remained neutral about whether they would have preferred that the escape room puzzles involved physical elements that they could print or receive via mail ($M = 2.8$, $MED = 3.0$, $SD = 1.4$), whereas participants of the in-class escape room neither agreed nor disagreed with the statement that they liked the physical puzzles better than the digital ones ($M = 3.0$, $MED = 3.0$, $SD = 1.1$). The positive attitudes of students towards computer-based puzzles are very encouraging for the

TABLE 3. Results of the student questionnaire.

	In-class			Remote				
Question	**M**	**MED**	**SD**	**M**	**MED**	**SD**	**Cliff's δ**	**p-value**
What is your general opinion on the escape room? (1 Very Poor - 5 Very Good)	4.6	5.0	0.6	4.3	4.0	0.8	0.26	**0.02**
Please, state your level of agreement with the following statements (1 Strongly disagree - 5 Strongly agree):								
The escape room allowed me to improve my knowledge of the course materials	4.1	4.0	0.8	3.9	4.0	1.0	0.10	0.38
I learned more with the escape room than I would have with a computer lab session	4.0	4.0	0.8	3.5	3.0	1.1	0.20	0.10
I liked the escape room better than a computer lab session	4.7	5.0	0.7	4.5	5.0	1.0	0.06	0.56
The escape room was fun for me	4.4	4.5	0.6	4.3	4.0	0.9	0.07	0.56
The escape room was an immersive experience	4.3	4.0	0.7	4.2	4.0	0.8	0.03	0.81
The escape room was a stressful experience	2.0	2.0	1.1	3.0	3.0	1.2	-0.47	**< 0.01**
The escape room was too hard	2.6	3.0	1.1	3.1	3.0	0.9	-0.29	**0.01**
The difficulty of the escape room lies in mastering the course materials	3.8	4.0	0.9	3.7	4.0	1.0	0.05	0.68
I think I was prepared enough to succeed in the escape room	3.4	3.5	1.3	3.1	3.0	1.3	0.13	0.28
The escape room was well-organized	4.5	5.0	0.6	4.2	4.0	0.9	0.15	0.18
The duration of the escape room (2h) was adequate	4.1	4.0	1.1	3.9	4.0	1.2	0.07	0.55
The hint approach was adequate	3.7	4.0	1.3	3.9	4.0	1.1	-0.09	0.46
I wish I received more help during the escape room	2.5	2.0	1.3	2.8	3.0	1.2	-0.20	0.10
The initial guidance provided was enough	4.0	4.0	0.9	3.3	3.5	1.3	0.28	**0.02**
The supervision of the activity was adequate	4.5	5.0	0.6	4.5	5.0	1.0	0.06	0.56
I would prefer the escape room to be an in-class activity	-	-	-	3.1	3.0	1.4	-	-
Despite the educational escape room being remote, I would have liked it to involve physical puzzles besides the digital ones	-	-	-	2.8	3.0	1.4	-	-
I liked the fact that the escape room had digital puzzles	-	-	-	4.4	4.0	0.7	-	-
I liked the physical puzzles better than the digital ones	3.0	3.0	1.1	-	-	-	-	-
I liked the fact that the escape room combined physical and digital puzzles	4.4	4.0	0.7	-	-	-	-	-
I liked participating in the escape room with a classmate	4.6	5.0	0.7	4.7	5.0	0.7	-0.06	0.49
I would rather have participated in the escape room on my own	1.4	1.0	1.0	1.5	1.0	1.0	-0.08	0.41
I would rather have been part of a larger team	2.1	1.5	1.2	3.1	3.0	1.5	-0.38	**< 0.01**
All the members of the team were equally involved in solving the puzzles	4.0	4.0	1.1	4.3	5.0	1.0	-0.12	0.29
	Yes	**No**		**Yes**	**No**		**ϕ**	**p-value**
Would you like other courses to include activities like this (even if it was not for a grade)?	100%	0%		98.1%	1.9%		0.09	0.89
Would you recommend other students to participate in the escape room (even if it was not for a grade)?	100%	0%		97.1%	2.9%		0.14	0.85

growing field of digital educational escape rooms since these puzzles allow to significantly reduce the cost of conducting the activity and enable an easy scalability of the puzzles, easing, this way, the development of this sort of activity in large-enrollment courses. In the remote educational escape room, students' opinions diverged when asked whether they would have preferred the escape room to be hosted as an in-class activity (M = 3.1, MED = 3.0, SD = 1.4), although most students were neutral about this idea. Although these results are in consensus with those of [34], this is not the case for all remote educational escape rooms, such as the one reported in [26], in which some students wished the activity had been "a real-life escape room" in order to "get the full experience". Despite the difference in overall opinions (the first questionnaire item analyzed) detected between the in-class and the remote experiences, the results obtained suggest that students did not feel they were missing on anything by participating in the escape room remotely. This finding is also very reassuring for educators since, due to the COVID-19 pandemic, they might be forced to switch from in-class to remote teaching overnight. Thus, knowing that students are receptive to remote educational escape rooms is comforting for educators thinking about adopting this type of learning activity into their teaching.

Regarding self-reported learning effectiveness, in both occasions students agreed that participating in the educational escape room allowed them to improve their knowledge (in-class: M = 4.1, MED = 4.0, SD = 0.8; remote: M = 3.9, MED = 4.0, SD = 1.0). This was an expected finding since prior research generally found that students perceive educational escape rooms as effective learning activities, both when they are conducted face-to-face [6], [9], [10], [12]–[30], [32], [35], [36] and remotely [26], [31], [34]. Both escape room experiences were perceived to be similarly beneficial for learning. Indeed, the difference in the responses to this questionnaire item between both escape room editions had a negligible effect size and was not found to be statistically significant. The authors of [26] also found a slightly lower self-reported learning effectiveness in the remote educational escape room, although the statistical significance of this difference was not reported. Moreover, these findings corroborate the results obtained in the learning effectiveness evaluation reported in the previous subsection, conducted by means of a pre-test and a post-test. In this regard, it is worth

indicating that there is a positive although mild correlation (Spearman's $\rho = 0.2$, p-value $= 0.03$) between the measured learning effectiveness (i.e. the difference between post- and pre-test scores) and the learning effectiveness self-reported by students who participated in the remote educational escape room, indicating that most students who thought they learned actually did, and vice versa. A slightly stronger correlation was found between these two variables in the in-class escape room (Spearman's $\rho = 0.3$, p-value $= 0.14$), although this correlation was not found to be statistically significant.

When compared with the computer lab sessions performed in the course, the majority of students who participated in either escape room agreed that they learned more in this activity than in a lab session, although participants of the in-class escape room agreed to a slightly greater extent (in-class: M = 4.0, MED = 4.0, SD = 0.8; remote: M = 3.5, MED = 3.0, SD = 1.1). However, this difference was not found to be statistically significant. Moreover, in both escape rooms, students strongly agreed that they liked participating in the educational escape room more than in a laboratory session (in-class: M = 4.7, MED = 5.0, SD = 0.7; remote: M = 4.5, MED = 5.0, SD = 1.0). It is worth mentioning that the in-class escape room was more similar to a lab session than the remote escape room (since in lab sessions students attend the same computer laboratory and work in pairs as well), so students who attended the in-class escape room could establish a comparison with more confidence than those that participated in the remote one. These results are consistent with those of [34], who found that students preferred a remote educational escape room rather than a computer lab session, and [9], [16], [22], [25], [32], who found that students preferred face-to-face educational escape rooms over other educational activities, although the specific comparison with programming lab sessions was only addressed in [32]. In addition, these findings indicate that educational escape rooms can be considered as an alternative to programming lab sessions since the former are more engaging for students and could produce tantamount positive impacts on students' learning, regardless of whether they are conducted in-class or remotely.

As far as the difficulty of the escape room is concerned, most students neither agreed nor disagreed with the statement that it was too hard (in-class: M = 2.6, MED = 3.0, SD = 1.1; remote: M = 3.1, MED = 3.0, SD = 0.9), although a larger percentage of the participants of the in-class escape room disagreed with this statement. The difference in responses was statistically significant and small to medium in size (Cliff's $\delta = -0.29$). On the other hand, most students in both escape rooms agreed that the difficulty of the escape room lied in mastering the course materials and not so much in the puzzle mechanics (in-class: M = 3.8, MED = 4.0, SD = 0.9; remote: M = 3.7, MED = 4.0, SD = 1.0). This implies that students spent most of their time trying to solve the programming tasks of the puzzles rather than struggling with game mechanics. The negligible and non-significant difference found on this item of the questionnaire between both escape rooms indicates that the transformation of the physical puzzles to a digital format did not alter this ratio. This also indicates that the difference in students' perceptions of the difficulty of the escape room was not due to the digitalization of the puzzles, but probably to the challenge of performing the activity remotely instead. In this regard, it is worth pointing out that prior works examining remote educational escape rooms found that some students experienced communication or collaboration problems that would not have occurred had the activities been carried out face-to-face [26], [34]. On the basis of these findings, instructors should be more attentive to students' needs in remote educational escape rooms, providing the support they need to successfully complete the activity.

Participants of the in-class educational escape room mostly disagreed with the statement that it was a stressful experience (M = 2.0, MED = 2.0, SD = 1.1), whereas remote participants' opinions were more diverse although mostly neutral (M = 3.0, MED = 3.0, SD = 1.2). The effect size of this difference was medium to large (Cliff's $\delta = -0.47$) and was found to be statistically significant, showing that the face-to-face educational escape rooms was less stressful than its remote counterpart. The most likely reason why students who participated in the in-class escape room found it less stressful than those who participated in the remote one is that the latter were more worried about experiencing some technical difficulty during the activity, which would have prevented them from completing it. In the in-class escape room, being side by side with their partners and the rest of the teams probably helped reduce stress as well. In the face-to-face educational escape rooms examined in [9], [24], students reported higher levels of stress than in the one analyzed in the present study. However, the cited works did not compare the students' stress levels in the face-to-face educational escape room with those of a remote counterpart. In turn, students who participated in the remote educational escape room examined in [34] reported a slightly lower level of stress than in the one analyzed in the present study. Again, this prior work did not establish a comparison with a face-to-face counterpart. Therefore, although no consensus exists across published literature about the stress levels that educational escape rooms can provoke in students, the evidence provided in this article confirms that these stress levels are increased when a face-to-face educational escape room is transformed into a remote one.

Morever, students agreed that both educational escape rooms had an appropriate duration (in-class: M = 4.1, MED = 4.0, SD = 1.1; remote: M = 3.9, MED = 4.0, SD = 1.2) and that the hint approach employed was adequate (in-class: M = 3.7, MED = 4.0, SD = 1.3; remote: M = 3.9, MED = 4.0, SD = 1.1). There were barely any differences in these characteristics between both escape rooms, so the fact that there were no significant differences in students' answers is not surprising. In turn, some logistical aspects of the activity did notably change from one experience to another, including the way it was organized and supervised. In this regard, most

students confidently agreed that the supervision of the activity was sufficient in both escape rooms (in-class: M = 4.5; MED = 5.0; SD = 0.6; remote: M = 4.5, MED = 5.0, SD = 1.0) and that they were well organized (in-class: M = 4.5, MED = 5.0, SD = 0.6; remote: M = 4.2, MED = 4.0, SD = 0.9). This finding indicates that conducting the activity online and supervising it through videoconferencing was perceived by the students of the remote escape room as highly as doing so in the computer laboratory with face-to-face supervision. However, students in the in-class educational escape room mostly agreed with the fact that they received sufficient initial guidance (M = 4.0, MED = 4.0, SD = 0.9), whereas the opinions of the participants of the remote escape room diverged and were more neutral (M = 3.3, MED = 3.5, SD = 1.3). This difference, which had a statistically significant small to medium effect size (Cliff's $\delta = 0.28$), probably stems from the fact that during the in-class educational escape room students could look around to take a peek at what their peers were doing, whereas in the remote educational escape room they could only see their screen, although they could talk to their partner via video conference throughout the whole activity and also access the support video conference room in case they needed help from the teacher. Notwithstanding, students in both escape rooms slightly disagreed, on average, that they wished they had received more help during the activity (in-class: M = 2.5, MED = 2.0, SD = 1.3; remote: M = 2.8, MED = 3.0, SD = 1.3), although more students thought otherwise in the remote escape room. In this regard, no statistically significant differences were found between both experiences.

Regarding team formation, most students in both escape rooms strongly agreed that they liked participating in the escape room in pairs (in-class: M = 4.6, MED = 5.0, SD = 0.7; remote: M = 4.7, MED = 5.0, SD = 0.7) rather than alone (in-class: M = 1.4, MED = 1.0, SD = 1.0; remote: M = 1.5, MED = 1.0, SD = 1.0). Moreover, participants of the in-class escape room disagreed with the fact that they would have preferred to form larger teams (M = 2.1, MED = 1.5, SD = 1.2), whereas the opinions of the participants of remote escape rooms were quite disparate (M = 3.1, MED = 3.0, SD = 1.5). This medium-sized (Cliff's $\delta = -0.38$) difference in responses probably stems from the fact that in the in-class escape room team members were huddled around one computer, so they felt that adding more members would only hamper their progress in the escape room, whereas in the remote escape room, since each student was connected through their own computer, there was room for more collaboration, so some students might have missed being in larger groups. A fact supporting this hypothesis is that in the remote educational escape room reported in [34], students strongly agreed that they liked participating in teams with several players. In addition, students surveyed in the present study agreed that all the members of the team were equally involved in the escape room, both in the in-class (M = 4.0, MED = 4.0, SD = 1.1) and the remote (M = 4.3, MED = 5.0, SD = 1.0) experiences, meaning that the pair-programming strategy can be effective when adopted remotely as well. However, further evidence is needed to confirm whether playing alone or in larger teams in remote educational escape rooms for learning programming would yield similar results.

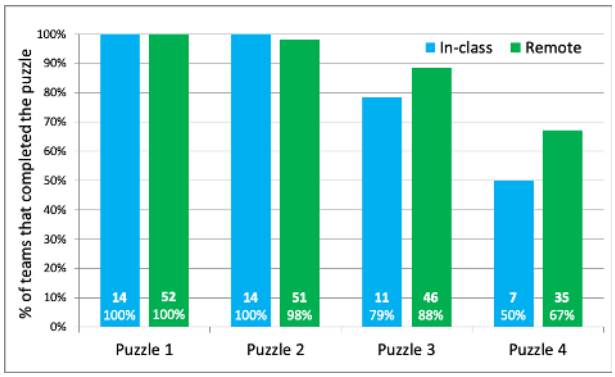

FIGURE 2. Number of teams that solved each puzzle in each escape room.

At the end of the questionnaire, students were asked to pose suggestions, comments and/or complaints. Overall, most students left very positive comments that gave reason to believe that they found the activity to be entertaining, interesting and didactic. Most comments addressed the same topics for both escape rooms, primarily emphasizing how much they had enjoyed the activity. Interestingly enough, no students from the remote educational escape room commented on the remote aspect of the activity. The fact that students overlooked this aspect of the activity suggests that their attitude towards the educational escape room does not depend on whether it is held face-to-face or at distance.

C. STUDENTS' PERFORMANCE

Fig. 2 shows the number and percentage of teams that solved each puzzle in both educational escape rooms. Although the percentage of puzzles solved was slightly higher in the remote educational escape room than in the in-class one, this difference was not found to be statistically significant when a Pearson's chi-squared test was applied. This was an expected result since both escape rooms had the same design characteristics (duration, team size, puzzle structure and hint approach). Hence, a relevant finding of this work is that whether an educational escape room is conducted remotely or not has no significant impact on its difficulty. This result proves that, although the students who participated in the remote educational escape room perceived the activity to be significantly more difficult than those who participated in the face-to-face one, performance was similar in both experiences. Similar correlation values were found between the number of puzzles solved and the item of the questionnaire addressing students' perceived difficulty for both escape rooms (in-class: Spearman's $\rho = -0.31$, p-value: 0.1; remote: Spearman's $\rho = -0.36$, p-value < 0.01), although this correlation was not significant for the in-class escape room. These findings indicate that students who did not solve all

TABLE 4. Summary of team attempts to obtain hints.

	Total quiz attempts to obtain hints					Successful quiz attempts (i.e. hints received)					Failed quiz attempts				
	M	MED	SD	Cliff's δ	p-value	M	MED	SD	Cliff's δ	p-value	M	MED	SD	Cliff's δ	p-value
In-class	7.7	5.0	7.0	-0.31	**< 0.01**	1.9	1.5	1.6	-0.35	**< 0.01**	5.8	3.0	6.3	-0.27	**0.03**
Remote	13.1	9.5	11.7			3.6	3.0	2.9			9.6	7.0	9.5		

the puzzles probably attribute it to the escape room being too difficult.

Another significant finding is that there exists a statistically significant correlation between measured learning effectiveness and the percentage of completion of the escape room puzzles achieved by the students who participated in both the in-class (Spearman's $\rho = 0.6$, p-value < 0.01) and the remote (Spearman's $\rho = 0.3$, p-value < 0.01) escape rooms, although this correlation was stronger in the in-class escape room. This finding corroborates that the more puzzles students were exposed to during the escape room, the greater their increase in knowledge was. This is also true for self-reported learning effectiveness, since a slight correlation was also found between this variable and the number of puzzles solved (in-class: Spearman's $\rho = 0.5$, p-value $= 0.02$; remote: Spearman's $\rho = 0.2$, p-value $= 0.05$). Since puzzles of both educational escape rooms covered the same learning objectives, these results were expected to be similar in both experiences.

Regarding hints, Table 4 shows, for both escape rooms, the average number of hints obtained by each of the participating teams (remote: M = 3.6, MED = 3.0, SD = 2.9; in-class: M = 1.9, MED = 1.5, SD = 1.6), i.e., attempts in which students passed the quiz. It also shows the average number of failed quiz attempts per team (remote: M = 9.6, MED = 7.0, SD = 9.5; in-class: M = 5.8, MED = 3.0, SD = 6.3), i.e., those in which students did not get enough answers right, as well as the average number of total quiz attempts to obtain hints performed by each team (remote: M = 13.1, MED = 9.5, SD = 11.7; in-class: M = 7.7, MED = 5.0, SD = 7.0). The table also includes the p-value obtained when a two-tailed Mann-Whitney U-test was conducted to compare the values obtained in both escape rooms, indicating that the differences are statistically significant for all three variables. Surprisingly, the figures recorded in the remote escape room are approximately twice as high as those recorded in the in-class one. The effect size was medium for the number of hints obtained (Cliff's $\delta = -0.35$) whereas for the total number of quiz attempts (Cliff's $\delta = -0.31$) and for the number of failed quiz attempts (Cliff's $\delta = -0.27$) it was small to medium. One possible explanation for the difference in the hint-related figures between both experiences is that, in the in-class escape room, pairs commonly shared a single computer in which they worked on the puzzles and attempted to obtain hints by solving a quiz, whereas, in the remote escape room, students participated from their homes, each using their own computer, which allowed them to use a 'divide and conquer' approach in which one team member worked on the puzzles while the other one tried to get a hint. Moreover, in the in-class escape room, the instructors who supervised the activity walked around the computer lab and occasionally intervened if students were on the wrong track, which was not the case in the remote escape room, since students did not share their screens with the instructors throughout the activity. Regardless of the reason for this difference, it becomes apparent that students behave differently when requesting hints in the remote educational escape room than when doing so face-to-face. This specific finding is of high relevance for instructors who wish to conduct an educational escape room remotely since they must take into account and prepare for the high demand for help from students during the activity.

Lastly, as expected, the quiz success rate was very similar in both escape rooms (in-class: 25%, remote: 27%), revealing that students' knowledge of the theoretical content of the course covered in the quiz questions was similar in both experiences. This was an expected result since students participated in the escape room at the same stage of the course in both occasions and the pool of questions used was the same both times. Another proof that the students' knowledge of the content covered by the escape room was very similar in both experiences is that no statistically significant difference was found between the pre-test scores obtained in each escape room.

VI. CONCLUSION, LIMITATIONS AND FUTURE WORK

This article reports the results of a comparative study in which two versions of the same educational escape room were conducted in a programming course at a higher education institution: one as an in-class activity and the other one remotely. Both experiences were evaluated and compared using the following three instruments: (1) a pre-test and a post-test to measure students' increase in knowledge, (2) a questionnaire to collect students' perceptions, and (3) a web platform for automatically recording data on students' interactions during the escape room. Although a previous work established a comparison between a remote educational escape room and a face-to-face one [26], such comparison only addressed students' perceptions, and the statistical significance of the differences in perceptions between both activities was not reported, preventing any statistically reliable conclusion from being drawn about the variations between the two experiences. Therefore, this article makes a novel and valuable contribution to the existing body of literature by providing, for the first time, a comprehensive and technically sound comparison between a face-to-face educational escape room and its remote counterpart in terms of learning effectiveness, students' perceptions, and students' performance.

Firstly, the results show that both the face-to-face and the remote educational escape rooms examined in this work

significantly improved students' knowledge. The difference in terms of learning gains between the two escape rooms was found to have a small to medium effect size, which was statistically significant at the significance level of 0.1, although not at the significance level of 0.05. According to the confidence intervals, the effect size of the difference between the learning gains produced by the face-to-face educational escape room and those produced by the remote educational escape room is, with a confidence of 95%, between 0.31 and 0.49, i.e., a small to medium effect size. Taking all these into account, it can be suggested that face-to-face educational escape rooms have a somewhat higher learning effectiveness than their remote counterparts.

Regarding self-reported learning effectiveness, no statistically significant differences were found in students' self-reported increase in learning between both escape rooms. Moreover, students rated the activity as fun and immersive to a similar extent in both experiences, although they perceived the remote escape room to be more stressful and difficult. However, when examining students' performance during the activity, the number of puzzles solved per team and the success rate were found to be very similar. Comparing students' performance between an in-class educational escape room and its remote counterpart is another novel contribution of this work. A significant change in students' behavior when requesting hints was detected since the students who participated in the remote educational escape room requested and obtained nearly twice as many hints as those who participated in the face-to-face one. The main reason for this change in behavior seems to be that in the remote escape room teams did not share a common device, which allowed one team member to request hints while the other one faced the escape room puzzles. Regarding the amount of help provided, results suggest that students in the remote educational escape room demanded more help, especially at the beginning of the activity. The results related to differences in students' behavior represent another unique finding of this comparative study.

Although the main contribution of this work is the comparison between a face-to-face educational escape room and its remote counterpart, the results obtained for each of these experiences individually constitute another valuable contribution of this article, as not many prior works have addressed all the aspects of educational escape rooms covered herein. For instance, some prior works [9], [23]–[25], [29], [30], [33], [34] have objectively evaluated the learning effectiveness of educational escape rooms, but only in one of them [34] the escape room was conducted remotely. Therefore, the evidence provided of the learning effectiveness of the educational escape rooms conducted in this work, especially of the remote one, is another valuable contribution to this field of research. The same applies to different aspects of students' perceptions (e.g., organization, difficulty and stress) as well as to their performance and behavior during the activity. In summary, the evidence provided by this article contributes to the better understanding of using escape rooms with educational purposes.

With the rise of online distance learning, not only as a result of the COVID-19 pandemic, but from long before through MOOCs (Massive Open Online Courses) and other online learning initiatives, instructors must find new ways of providing highly engaging group activities such as educational escape rooms in online settings. The results presented in this work are therefore useful and encouraging for instructors that wish to carry out these novel educational activities in distance learning scenarios. Indeed, these results provide further proof that educational escape rooms are effective and engaging learning activities even when they are conducted remotely, although they also suggest that conducting these activities face-to-face can be more beneficial for students' learning. On the basis of our findings, we recommend instructors to pay special attention to certain aspects to ensure that educational escape rooms run smoothly when conducted remotely, namely providing enough initial guidance to students to prevent them from feeling stressed or perceiving the activity as too difficult, and making sure that they have help available throughout the activity in case they get stuck at a certain puzzle (e.g., by providing hints) or they experience technical issues (e.g., by facilitating a support video conference link).

It is worth mentioning that conducting both educational escape rooms for such a large course could not have been possible without using the Escapp platform [47], since it made possible to perform otherwise unfeasible tasks such as tracking students' progress, which allowed to issue automatic hints for each specific situation and, in the case of the remote escape room, to synchronize the progress between team members, enabling real-time remote collaboration. The use of a software system such as Escapp to conduct both face-to-face and remote educational escape rooms constitutes another unique contribution of this article. In view of the facts previously described, we recommend instructors to use specialized software tools such as Escapp for running both face-to-face and remote educational escape rooms.

It is important to acknowledge several limitations of this study. First, the most obvious limitation is the small sample size of the face-to-face educational escape room, as already acknowledged in [33]. Moreover, an additional limitation is that the participants of the study were volunteer students instead of randomly selected, and that the participants of each escape room took the course in two consecutive academic years. However, it should be remarked that both escape rooms were conducted in the exact same course and students' profiles were practically equal from one year to the next. In addition, the puzzles of both educational escape rooms were not exactly the same since, inevitably, some of the puzzles in the face-to-face escape room had to be completely digitalized in order to conduct the experience remotely. Lastly, some of the aspects of the two educational escape room experiences examined in this work could have been more deeply analyzed using additional research instruments such as observation through video recording and interviews, which would have allowed to collect more quantitative and qualitative data.

Due to the novelty of the field of educational escape rooms in general, and of remote educational escape rooms specifically, several lines of research can be addressed to contribute to this growing field. First, an interesting line of research would be to examine educational escape rooms conducted remotely as self-paced activities instead of multitudinous events. Specifically, MOOCs constitute a favorable learning environment to investigate that specific approach to educational escape rooms. Moreover, another line of research worth pursuing is evaluating how different design characteristics of educational escape rooms may affect players' perceptions, learning effectiveness, performance, and behavior; for instance, by comparing different team sizes or hint approaches. Furthermore, future studies could also make novel contributions to the field by examining educational escape rooms using additional research instruments such as observation through video recording, sensor-based tracking or interviews. Data collected via these instruments could provide a deeper understanding of the students' experience during these activities. Lastly, it would be of great interest to study the usefulness of the learning analytics gathered during educational escape rooms to automatically issue real-time interventions and how these can impact students' experience.

REFERENCES

[1] A. V. Lama, "Millennial leisure and tourism: The rise of escape rooms," *Cuadernos de Turismo*, vol. 41, pp. 743–746, 2018.
[2] S. Nicholson. (2015). *Peeking Behind the Locked Door: A Survey of Escape Room Facilities*. Accessed: Sep. 9, 2019. [Online]. Available: http://scottnicholson.com/pubs/erfacwhite.pdf
[3] SCRAP. (2007). *A Party of Riddles, Puzzles, Curry and Beer (Translation)*. Accessed: Aug. 8, 2020. [Online]. Available: https://realdgame.jp/event/nazotokinoutage.html
[4] *World of Escapes*. Accessed: Dec. 10, 2020. [Online]. Available: https://worldofescapes.com
[5] S. J. Clarke, D. J. Peel, S. Arnab, L. Morini, H. Keegan, and O. Wood, "EscapED: A framework for creating educational escape rooms and interactive games to for higher/further education," *Int. J. Serious Games*, vol. 4, no. 3, pp. 73–86, Sep. 2017.
[6] C. Jiménez, R. Lafuente, M. Ortiz, L. Bruton, and V. Millán, "Room escape: Propuesta de Gamificación en el grado de fisioterapia," in *Proc. Actas del 3rd Congr. Nac. Innovación Educ. y Docencia en Red*. Valencia, Spain: Universitat Politècnica València, 2017, pp. 537–551.
[7] C. Borrego, C. Fernández, I. Blanes, and S. Robles, "Room escape at class: Escape games activities to facilitate the motivation and learning in computer science," *J. Technol. Sci. Educ.*, vol. 7, no. 2, pp. 162–171, 2017.
[8] S. R. Monaghan and S. Nicholson, "Bringing escape room concepts to pathophysiology case studies," *HAPS Educator*, vol. 21, no. 2, pp. 49–65, Aug. 2017.
[9] H. N. Eukel, J. E. Frenzel, and D. Cernusca, "Educational gaming for pharmacy students–design and evaluation of a diabetes-themed escape room," *Amer. J. Pharmaceutical Educ.*, vol. 81, no. 7, p. 6265, Sep. 2017.
[10] A. I. V. Vörös and Z. Sárközi, "Physics escape room as an educational tool," in *Proc. AIP Conf.*, vol. 1916, 2017, Art. no. 050002.
[11] P. Fotaris and T. Mastoras, "Escape rooms for learning: A systematic review," in *Proc. 13th Eur. Conf. Games Based Learn. (ECGBL)*, L. Elbaek, G. Majgaard, A. Valente, and S. Khalid, Eds. Reading, U.K.: Academic Conferences and Publishing International Limited, 2019, pp. 235–243.
[12] M. Hermanns, B. Deal, A. M. Campbell, S. Hillhouse, J. B. Opella, C. Faigle, and R. H. Campbell, "Using an 'escape room' toolbox approach to enhance pharmacology education," *J. Nurs. Educ. Pract.*, vol. 8, no. 4, pp. 89–95, 2018.
[13] V. Adams, S. Burger, K. Crawford, and R. Setter, "Can you escape? Creating an escape room to facilitate active learning," *J. Nurses Prof. Develop.*, vol. 34, no. 2, pp. E1–E5, 2018.
[14] J. L. Gómez-Urquiza, J. Gómez-Salgado, L. Albendín-García, M. Correa-Rodríguez, E. González-Jiménez, and G. A. C.-D. L. Fuente, "The impact on nursing students' opinions and motivation of using a 'nursing escape room' as a teaching game: A descriptive study," *Nurse Educ. Today*, vol. 72, pp. 73–76, Jan. 2019.
[15] M. Boysen-Osborn, S. Paradise, and J. Suchard, "The toxiscape hunt: An escape room-scavenger hunt for toxicology education," *J. Educ. Teach. Emerg. Med.*, vol. 3, no. 1, pp. 9–19, 2018.
[16] J. Cain, "Exploratory implementation of a blended format escape room in a large enrollment pharmacy management class," *Currents Pharmacy Teaching Learn.*, vol. 11, no. 1, pp. 44–50, Jan. 2019.
[17] N. Brown, W. Darby, and H. Coronel, "An escape room as a simulation teaching strategy," *Clin. Simul. Nursing*, vol. 30, pp. 1–6, May 2019.
[18] A. E. Kinio, L. Dufresne, T. Brandys, and P. Jetty, "Break out of the classroom: The use of escape rooms as an alternative teaching strategy in surgical education," *J. Surgical Educ.*, vol. 76, no. 1, pp. 134–139, Jan. 2019.
[19] J. Guckian, A. Sridhar, and S. J. Meggitt, "Exploring the perspectives of dermatology undergraduates with an escape room game," *Clin. Exp. Dermatol.*, vol. 45, no. 2, pp. 153–158, Mar. 2020.
[20] N. Dietrich, "Escape classroom: The Leblanc process—An educational 'escape game,'" *J. Chem. Educ.*, vol. 95, no. 6, pp. 996–999, Jun. 2018.
[21] M. Ferreiro-González, A. Amores-Arrocha, E. Espada-Bellido, M. J. Aliano-Gonzalez, M. Vázquez-Espinosa, G. F. Barbero, A. V. González-de Peredo, P. Sancho-Galán, J. A. Álvarez-Saura, and C. Cejudo-Bastante, "Escape classroom: Can you solve a crime using the analytical process?" *J. Chem. Educ.*, vol. 96, no. 2, pp. 267–273, 2019.
[22] K. Jambhekar, R. P. Pahls, and L. A. Deloney, "Benefits of an escape room as a novel educational activity for radiology residents," *Academic Radiol.*, vol. 27, no. 2, pp. 276–283, Feb. 2020.
[23] A. Clauson, L. Hahn, T. Frame, A. Hagan, L. A. Bynum, M. E. Thompson, and K. Kiningham, "An innovative escape room activity to assess student readiness for advanced pharmacy practice experiences (APPEs)," *Currents Pharmacy Teach. Learn.*, vol. 11, no. 7, pp. 723–728, Jul. 2019.
[24] L. M. Caldas, H. N. Eukel, A. T. Matulewicz, E. V. Fernández, and K. L. Donohoe, "Applying educational gaming success to a nonsterile compounding escape room," *Currents Pharmacy Teaching Learn.*, vol. 11, no. 10, pp. 1049–1054, Oct. 2019.
[25] S. Cotner, K. M. Smith, L. Simpson, D. S. Burgess, and J. Cain, "1311. incorporating an 'escape room' game design in infectious diseases instruction," *Open Forum Infectious Diseases*, vol. 5, no. 1, p. S401, 2018.
[26] J. W. J. Ang, Y. N. A. Ng, and R. S. Liew, "Physical and digital educational escape room for teaching chemical bonding," *J. Chem. Educ.*, vol. 97, no. 9, pp. 2849–2856, Sep. 2020.
[27] D. D. L. Flor, J. A. Calles, J. J. Espada, and R. Rodríguez, "Application of escape lab-room to heat transfer evaluation for chemical engineers," *Educ. Chem. Eng.*, vol. 33, pp. 9–16, Oct. 2020.
[28] S. C. Brady and E. C. Andersen, "An escape-room inspired game for genetics review," *J. Biol. Educ.*, pp. 1–12, Dec. 2019.
[29] S. Mystakidis, E. Cachafeiro, and I. Hatzilygeroudis, "Enter the serious E-scape room: A cost-effective serious game model for deep and meaningful E-learning," in *Proc. 10th Int. Conf. Inf., Intell., Syst. Appl. (IISA)*, Jul. 2019, pp. 1–6.
[30] S.-Y. Huang, Y.-H. Kuo, and H.-C. Chen, "Applying digital escape rooms infused with science teaching in elementary school: Learning performance, learning motivation, and problem-solving ability," *Thinking Skills Creativity*, vol. 37, Sep. 2020, Art. no. 100681.
[31] M. Monnot, S. Laborie, G. Hébrard, and N. Dietrich, "New approaches to adapt escape game activities to large audience in chemical engineering: Numeric supports and students' participation," *Educ. Chem. Eng.*, vol. 32, pp. 50–58, Jul. 2020.
[32] S. Lopez-Pernas, A. Gordillo, E. Barra, and J. Quemada, "Examining the use of an educational escape room for teaching programming in a higher education setting," *IEEE Access*, vol. 7, pp. 31723–31737, 2019.
[33] S. Lopez-Pernas, A. Gordillo, E. Barra, and J. Quemada, "Analyzing learning effectiveness and students' perceptions of an educational escape room in a programming course in higher education," *IEEE Access*, vol. 7, pp. 184221–184234, 2019.
[34] A. Gordillo, D. Lopez-Fernandez, S. Lopez-Pernas, and J. Quemada, "Evaluating an educational escape room conducted remotely for teaching software engineering," *IEEE Access*, vol. 8, pp. 225032–225051, 2020.
[35] C. Jiménez, N. Arís, Á. A. M. Ruiz, and L. Orcos, "Digital escape room, using Genial.Ly and a breakout to learn algebra at secondary education level in Spain," *Educ. Sci.*, vol. 10, no. 10, p. 271, Oct. 2020.

[36] A. Fuentes-Cabrera, M. E. Parra-González, J. López-Belmonte, and A. Segura-Robles, "Learning mathematics with emerging methodologies—The escape room as a case study," *Mathematics*, vol. 8, no. 9, p. 1586, Sep. 2020.
[37] M. Prince, "Does active learning work? A review of the research," *J. Eng. Educ.*, vol. 93, no. 3, pp. 223–231, Jul. 2004.
[38] C. C. Bonwell and J. A. Eison, *Active Learning: Creating Excitement in the Classroom. ASHE-ERIC Higher Education Reports*. Washington, DC, USA: ERIC Clearinghouse on Higher Education, 1991.
[39] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*. New York, NY, USA: Harper & Row, 1990.
[40] J. L. Plass, B. D. Homer, and C. K. Kinzer, "Foundations of game-based learning," *Educ. Psychologist*, vol. 50, no. 4, pp. 258–283, Oct. 2015.
[41] M. Prensky, "Fun, play and games: What makes games engaging," in *Digital Game-Based Learning*. New York, NY, USA: McGraw-Hill, 2001, pp. 1–31.
[42] M. J. Vergne, J. D. Smith, and R. S. Bowen, "Escape the (remote) classroom: An online escape room for remote learning," *J. Chem. Educ.*, vol. 97, no. 9, pp. 2845–2848, Sep. 2020.
[43] H. Eukel, J. Frenzel, K. Frazier, and M. Miller, "Unlocking student engagement: Creation, adaptation, and application of an educational escape room across three pharmacy campuses," *Simul. Gaming*, vol. 51, no. 2, pp. 167–179, Apr. 2020.
[44] A. M. Ho, "Unlocking ideas: Using escape room puzzles in a cryptography classroom," *Primus*, vol. 28, no. 9, pp. 835–847, Oct. 2018.
[45] L. Williams and R. L. Upchurch, "In support of student pair-programming," *ACM SIGCSE Bull.*, vol. 33, no. 1, pp. 327–331, Mar. 2001.
[46] C. McDowell, L. Werner, H. Bullock, and J. Fernald, "The effects of pair-programming on performance in an introductory programming course," in *Proc. 33rd SIGCSE Tech. Symp. Comput. Sci. Educ.*, vol. 34, 2002, pp. 38–42.
[47] S. Lopez-Pernas, A. Gordillo, E. Barra, and J. Quemada, "Escapp: A Web platform for conducting educational escape rooms," *IEEE Access*, vol. 9, pp. 38062–38077, 2021.
[48] J. Cohen, "A power primer," *Psychol. Bull.*, vol. 112, no. 1, pp. 155–159, 1992.
[49] J. Romano, J. D. Kromrey, J. Coraggio, and J. Skowronek, "Appropriate statistics for ordinal level data: Should we really be using t-test and Cohen'sd for evaluating group differences on the NSSE and other surveys?" in *Proc. Annu. Meet. Florida Assoc. Institutional Res.*, 2006, pp. 1–3.

SONSOLES LÓPEZ-PERNAS (Graduate Student Member, IEEE) received the bachelor's and master's degrees in telecommunications engineering from the Universidad Politécnica de Madrid (UPM), in 2016 and 2018, respectively, where she is currently pursuing the Ph.D. degree in telematics engineering. Since 2015, she has been working as a Researcher with the Department of Telematics Engineering, UPM, participating in different projects, such as FIWARE and eid4U. Her research interests include technology enhanced learning and real-time analytics, with a focus on authoring tools, educational data mining, and educational escape rooms.

ALDO GORDILLO received the degree in telecommunications engineering and the Ph.D. degree in telematics engineering from the Universidad Politécnica de Madrid (UPM), in 2012 and 2017, respectively. From 2012 to 2017, he was a Research and a Development Engineer with the Telematics Engineering Department, UPM. He is currently an Assistant Professor with the Computer Science Department, UPM. His research interests include technology-enhanced learning, with a special focus on creation, evaluation, and dissemination of e-learning resources, computer science education, game-based learning, and e-learning systems.

ENRIQUE BARRA received the Ph.D. degree in telematics engineering with a minor in multimedia and technology enhanced learning from the Universidad Politécnica de Madrid (UPM). He has participated in many European projects, such as GLOBAL, FIWARE, and C@R. He is currently involved in several projects contributing to the generation and distribution of educational content in TEL environments. His research interests include videoconferencing, games in education, and social networks in education.

JUAN QUEMADA (Life Member, IEEE) is currently a Full Professor with the Telematics Engineering Department, Universidad Politécnica de Madrid (UPM). He is also the Head of the Internet NG UPM Research Group, the Telefonica Chair of UPM for next generation Internet, and the UPM Representative at the World Wide Web Consortium. He has authored a large variety of publications. His research interests include collaborative and social application architecture for the Internet and the Web, including cloud computing, where he has a strong involvement in European and Spanish research.