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Escapp: A Web Platform for Conducting Educational Escape Rooms

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ABSTRACT Educational escape rooms are emerging as a new type of learning activity with the potential to enhance students' learning through highly engaging experiences. However, conducting educational escape rooms effectively is very complex and there are no software tools available for this purpose. This lack of support is hindering the widespread use and adoption of these activities. This article presents Escapp, a web platform that allows teachers to conduct effective and highly engaging educational escape rooms. The platform has been used for conducting three different educational escape rooms (one face-to-face and two remotely) in three higher education settings. Three case studies were conducted to empirically evaluate the usefulness of Escapp for conducting these activities, which involved more than 400 students. On the one hand, a questionnaire was administered to students to gather their opinions on the Escapp platform, obtaining very positive results in terms of overall usefulness, usability and engagement. On the other hand, data automatically recorded by Escapp during the three educational escape rooms are presented as evidence of the high number of student interactions that take place during activities of this kind and the need of using a software system for conducting them in an effective way. The results of this article show that Escapp is a well-suited solution for conducting effective face-to-face and remote educational escape rooms.

INDEX TERMS Breakout games, collaborative learning, distance learning, educational activities, educational technology, escape rooms, game-based learning, gamification, software tools.

I. INTRODUCTION

According to [1], escape rooms can be defined as “live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal (usually escaping from the room) in a limited amount of time”. In addition to having become one of the most popular leisure activities in the last few years, the potential of escape rooms to foster teamwork, leadership, creative thinking, and communication [2]–[7] has led them to make the leap into the education sector.

As if the benefits of using ludic escape rooms in academic settings were not enough, teachers have started to create actual educational escape rooms: escape rooms that require students to master field-specific knowledge and skills in order to solve the puzzles and succeed in the activity. Educational

escape rooms can be classified into two types according to how they are conducted. On the one hand, face-to-face educational escape rooms, which are the most common type, are those conducted as in-person activities in a closed place such as a classroom or a laboratory. On the other hand, remote educational escape rooms are those in which the setting where the activity takes place is virtual, the students are separated in space, and teammates participate simultaneously using their own devices. Furthermore, regardless of whether they are conducted face-to-face or remotely, educational escape rooms can also be classified as physical or virtual depending on whether the puzzles and resources involved are digital or not. In this regard, it should be indicated that virtual educational escape rooms are those which exclusively use digital puzzles and resources.

Educational escape rooms have emerged as a new type of learning activity with the potential to enhance students' learning through highly engaging experiences.

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Different researchers have reported on using this sort of activities in a wide variety of fields including nursing [8]–[10], medicine [11]–[15], physiotherapy [16], pharmacy [17]–[23], physics [24], chemistry [25]–[30], biology [31], [32], cryptography [33], mathematics [34], [35], and computer science, [36]–[39]. These studies have provided firm experimental evidence that educational escape rooms can produce positive impacts on student engagement [8]–[14], [16]–[22], [25], [26], [28]–[32], [34]–[38], [40] and learning [20], [21], [32], [37], [38], [40], both when they are conducted face-to-face [8]–[14], [16]–[22], [25], [26], [28], [29], [31], [32], [34]–[37], [40] and remotely [28], [30], [38]. The potential of educational escape rooms to increase students' motivation and knowledge, coupled with the fact that they can be applied in a wide variety of knowledge areas and settings, has made them an increasingly popular learning activity at all stages of education [41], [42].

When students participate in an educational escape room, they usually start by forming teams and getting acquainted with the instructions of the activity. In some cases, the whole class participates at the same time but, more often than not, only a few or even just one team can play at a time, which means that they need to book a slot to participate in the escape room in advance. Once the escape room starts, there is often a backstory that is revealed to students at the very beginning, usually by means of a video or interactive presentation, which also discloses the goal that students need to accomplish in a given time limit. The goal may consist in escaping a room or achieving another specific objective such as defusing an explosive device, finding a missing person or solving a murder, to name a few examples [1]. Thereafter, the countdown officially starts, which is usually shown to the students so they are always aware of the time they have left. Students may then begin to solve the different puzzles that make up the escape room, which lead them to accomplish the final objective. The puzzles may have to be solved in a linear sequence, in no particular order, or a mix of both. These puzzles may be of very different natures and are usually very dependent on the field of knowledge. They usually intertwine classic ludic escape room puzzle mechanics (e.g. deciphering codes, opening locks, finding hidden elements, substituting symbols, identifying patterns, etc.) with domain-specific tasks (e.g. performing math calculations, operating laboratory equipment, mixing chemical substances, interpreting medical results, writing programming code, etc.). Generally, clues are provided to students or are available for them to find during an educational escape room. These clues are aimed at helping them solve the different puzzles. However, clues that are not useful to solve the puzzles and whose function is simply to act as distractors or decorate the experience can also be included. If a team gets stuck while solving a puzzle, they can usually get help by asking the teachers or in other ways such as via pre-made hints. All the teams that manage to accomplish the escape room goal before the time is over are considered to be successful in the activity.

To handle all the actions that must be performed when conducting an educational escape room, a great effort is needed on the part of the teachers. First, prior to the activity taking place, teachers must provide a way for students to register their teams and book a slot to participate, if needed. Then, they must provide students with a set of instructions explaining the rules of the activity (dates, preparation, assessment, etc.). The day of the activity, teachers need to arrange all the materials needed for the escape room and take attendance. Once the escape room activity starts, they also need to project the introductory video or let students know in any other way the narrative of the escape room as well as the final goal they need to accomplish. During an educational escape room, everyone must be always aware of the time they have left to complete it, which is usually done by projecting a countdown for all students to see.

Students often get stuck when trying to solve the different puzzles and, if there is no intervention that allows them to solve the puzzle in which they are stuck and continue moving forward in a reasonable time, there is a high risk of students getting frustrated and the activity not being effective. Normally, teachers hand out hints to students whenever they ask for help, either for free or in exchange for something like a hint card provided at the beginning of the escape room. Sometimes, requesting a hint may even take away points from the score of the students' team or subtract time from their countdown. Although teachers usually come up with hints on the spur of the moment, on occasions they have pre-set hints available for each puzzle in the escape room. Manually providing the necessary hints and help in a timely manner during an educational escape room can become overwhelming or even impossible if the student-teacher ratio is high; especially taking into account that in order to provide useful hints to students, it is necessary to know on which part of the escape room each team is working at all times. Therefore, there is a need to track students' performance in order to detect students that need help or lagging teams, as well as a need to provide them with useful help in a timely manner. Tracking students' progress is also necessary in order to avoid cheating, for instance, ensuring that students do not skip any puzzle and that they solve the escape room in the order stipulated by the teacher. In addition, custom events could take place for teams when they reach a certain point in the escape room, such as showing a new video with a plot twist. Without a mechanism to manage these events automatically, teachers would have to be attentive to the progress of each team in order to carry out the necessary actions at the right time.

After the escape room is over, teachers may need to grade the activity. Given that it may be unfair to grade students based only on whether they attend or successfully complete the escape room, teachers could need more accurate grading (e.g. by taking into account the number of puzzles solved by each team), which reinforces the need to closely monitor the progress of each student. Furthermore, from such monitoring teachers could extract valuable insights, namely, how long it takes each team to solve the different puzzles or for which

of them they needed more hints, which can be very useful to enhance the escape room for future editions, as well as to identify, among other things, which concepts need to be further reviewed in class. Despite the great value that can be extracted from this information, prior works on educational escape rooms reported in the literature barely analyze data gathered at run-time and most of them do not address this issue at all. This is not surprising since collecting data at that level of detail without using software systems is extremely difficult or even infeasible, especially in remote settings or crowded classrooms. For instance, in [8], more than twenty sessions of the escape room had to be conducted in order to accommodate all the participants while ensuring that they were adequately monitored.

Taking into account all the actions previously described that need to be performed when conducting an educational escape room, it becomes clear that a software system is needed for effectively accomplishing this task. On the one hand, effective and reliable monitoring of students' performance throughout an escape room requires to use a software system capable of performing such monitoring in an automatic and systematic way. In escape rooms with multiple teams of students, it is impossible (or at least tremendously arduous and error-prone) to manually record, for each team, which puzzles they have solved, how much time they have spent solving each puzzle, which hints they have obtained, which clues they have found, etc. On the other hand, a software system is also essential in order to automatically detect students who need help or who are at risk of demotivation and provide them with useful hints in a timely manner, thus, allowing them to progress toward successfully completing the escape room and hence, toward accomplishing the learning objectives of the activity. Additionally, such system would open up a sea of possibilities for conducting educational escape rooms since it would allow including gamification elements such as leaderboards and points in order to promote competition among students, generating learning analytics (which could be used by the teachers during the activity or after it is over), or automatically grading students. Lastly, it also should be taken into account that a software system of this kind would be able to ease different actions required to conduct an educational escape room such as team formation, enrollment and shift management, roll call, content management, and event execution.

The need for a software system to effectively conduct educational escape rooms as described above is more critical when these activities are conducted remotely than when they are conducted face-to-face. If monitoring students in face-to-face educational escape rooms without using software systems is extremely difficult and unreliable, doing so in remote educational escape rooms is practically impossible. Furthermore, performing the remaining tasks involved in conducting an educational escape room (e.g. enrollment, team formation, roll call, hint delivery, content management or event execution) is also more complicated in a remote setting than in an in-class setting. A software system capable of

conducting remote educational escape rooms without teacher intervention and with no capacity limit would open up new and interesting possibilities such as conducting these activities in other educational settings such as MOOCs (Massive Open Online Courses) and other self-paced online courses.

In view of the above facts and considerations, it becomes clear that the lack of software tools specifically designed for conducting educational escape rooms is hampering the use and adoption of these learning activities, as well as preventing them to achieve their full potential.

This article presents Escapp, a web platform that allows teachers to effectively conduct face-to-face and remote educational escape rooms, aimed at reducing some of the barriers standing in the way of educators trying to incorporate educational escape rooms into their teaching. Specifically, Escapp is capable of assisting instructors in all the steps of the process of conducting an educational escape room: student registration, team formation, control of the execution of the activity (management of resources, narrative events, and gamification elements during the activity), progress monitoring, hint management, and grading. Escapp has been used to conduct three different educational escape rooms in higher education settings: one face-to-face and two remotely. The use of Escapp in each of these educational escape rooms has been evaluated in an independent case study. A student questionnaire was conducted after running each of these educational escape rooms with the goal of evaluating students' opinions on the use of Escapp. The data gathered by Escapp during the three activities are also presented as evidence of the high number of student interactions that take place during activities of this kind and the need of using a software system for conducting them in an effective way. The results of this work show that Escapp is a well-suited solution for conducting effective face-to-face and remote educational escape rooms.

The rest of the article is structured as follows. Existing literature on monitoring and supervising educational escape rooms is reviewed in the next section, as well as existing resources and software tools for building escape room puzzles and conducting other educational activities. Section III describes the Escapp platform in detail. Section IV explains the methodology followed to evaluate the platform. Section V shows and discusses the results obtained from this evaluation. Lastly, Section VI finishes with the conclusions of the article and an outlook on future work.

II. RELATED WORK

In most educational escape rooms reported in the literature, authors usually overlook the topic of monitoring the activity, especially tracking student progress and the challenge it represents in large-enrollment courses. In most of these experiences, teachers were present in the classroom and manually tracked students' performance throughout the activity, providing them with help when they needed it. For instance, in [8], a moderator was present during the escape room to hand out hints when students got stuck, along with a

timekeeper to record the time needed to complete each puzzle. Moreover, in [15], a supervisor was in charge of determining whether students' answers to the different puzzles were right or wrong, enabling them to advance to the next one. In [10], it was the students themselves who were in charge of writing down the time remaining on the clock upon completion of the escape room for their peers to see. A few works have reported that students were monitored by means of video surveillance [14], [20], [21], [23], [39], which is more common in escape rooms in which only one team participates at a time and participants are actually "locked" in a physical room. Similarly, in the study reported in [11], the activity organizers observed participants' progress throughout the escape room behind a one-way mirror and recorded the time to completion, the number of hints provided, and the team collaboration strategies used. However, not all educational escape rooms required teacher intervention during the activity. For instance, in [18], a pre-set hint card was elaborated for each puzzle, allowing students to get the help they needed without communicating with the teacher. For the purpose of automatically keeping track of students' progress, the authors of [43] used Moodle questionnaires to represent each of the challenges in the escape room, requiring students to provide the right answer to each one of them before unlocking the next one.

A few resources aimed at helping teachers build educational escape room puzzles had been reported in the literature. One of these resources is Breakout EDU [44], a platform which sells a series of toolkits with physical ready-to-use materials for educational escape rooms, such as black lights, combination locks, key locks, lockable boxes, etc. [10], [15]. Another example is Genial.ly [45], an authoring tool that allows to create escape room-like digital games such as the one described in [34], which was used in a mathematics course. This authoring tool can help instructors without strong computer skills create their own virtual escape rooms in the form of digital games, similarly to how they create slideshows. However, it does not provide important features for managing and conducting educational escape rooms such as student enrollment, team formation, shift scheduling, hint strategies involving human intervention or time restrictions, remote collaboration, and integration of external puzzles (physical or virtual). Another resource intended for helping instructors create puzzles for educational escape rooms is the one reported by [46], who designed an open-source escape room decoder and used it successfully in an educational escape room with over 450 participants. Moreover, the authors of [47] created a web tool to help escape room designers structure and outline their puzzles, as well as to access useful information available on educational escape rooms in a centralized way.

As can be derived from the studies cited, to the knowledge of the authors, no previous work in the literature has reported on the use of a software system specifically designed for conducting face-to-face and remote educational escape rooms or a software system that provides all the distinct features

that conducting these learning activities require. Without using systems of this kind, educators that conduct educational escape rooms are not capable of taking full advantage of the potential of these novel activities despite investing a great deal of time and effort in their development.

Although currently educational escape rooms are not conducted using software systems, relying on software tools to conduct other types of educational activities has become increasingly popular among teachers in recent years. For instance, the use of audience response systems has practically become the norm in most institutions, since they have the potential to positively impact learning outcomes [48]. These systems allow students to answer electronically displayed multiple choice questions using a remote control device [49] (which can be physical or digital). Audience response systems can foster student participation in the classroom avoiding the fear of being judged, especially if they integrate gamification elements (such as leaderboards and points), and help teachers gather instant feedback from every student in an easy and convenient way. In fact, prior studies have reported on the increase in student knowledge and engagement of using applications such as Socrative [50], [51], Kahoot [51]–[53], Quizziz [53] or Mentimeter [54] in the classroom.

One software application that enables more complex interactions than audience response systems is Padlet. Authors of [55] used Padlet to host a synchronous online debate and found that the tool can be used for collaborative learning since students could build knowledge and generate new ideas by using it. Using a completely different approach, the Kaggle platform enables collaborative learning in the area of data science and machine learning by providing an environment to host data competitions for students, which have proven to have a positive impact on student knowledge [56]. In the same line, with the aim of introducing block programming competitions in the classroom, the authors of [57] designed and developed "RITA en RED", a collaborative space for the creation and analysis of programmed robot strategies, which have proven to foster student motivation and learning. Authors of [58] reviewed several software tools for conducting programming competitions, such as Mooshak, which has been successfully used for hosting activities of this kind in the classroom [59]. Similarly, [60] created FLEQ, a tournament management software that allows participants to synchronously play against other players, taking care of scheduling matches, and tracking data for classification and tracing. Moreover, the authors of [61] presented FGAWeb, a web platform that can be utilized by instructors to create, edit and reuse quiz or puzzle game activities, offering an API to retrieve game data from third-party applications, as well as game learning analytics. However, no evidence on the effectiveness of this platform for conducting such activities has been found in the literature. Lastly, it is worth mentioning that several software tools have been developed for conducting capture-the-flag (CTF) games in the classroom [62]–[64], which are hacking competitions to learn cybersecurity concepts.

In view of the dearth of resources aimed at helping teachers conduct face-to-face and remote educational escape rooms and the positive results obtained from using software systems for conducting other types of educational activities, it is our belief that a software system specifically designed for conducting educational escape rooms would greatly contribute to the widespread adoption of these activities in an effective way.

III. THE ESCAPP PLATFORM

This section presents Escapp, an open-source web platform for conducting educational escape rooms. The source code of Escapp, installation instructions and user manual are publicly available at <https://github.com/ging/escapp>. Escapp is capable of assisting instructors in all aspects of conducting an activity of this kind, both face-to-face in the classroom as well as in online distance learning settings. A requirement for all educational escape rooms conducted with Escapp is that they need to be computer-based. This does not mean that they cannot include physical puzzles, but rather that students need to interact with Escapp during the activity, either directly or through other software applications. In this regard, it is worth clarifying that Escapp has been designed for conducting escape room experiences that combine physical and digital puzzles. Another distinct characteristic of Escapp-driven educational escape rooms is that they need to have a linear structure. This means that participants must solve the puzzles in a specific sequence (i.e. a puzzle must be solved before advancing to the next one). Linear educational escape rooms encourage all members of a team to work together to solve each puzzle and also allow for a better follow-up of students' progress since, by keeping track of the puzzles solved by each team, teachers can easily be aware of exactly what puzzle is being faced by each team, whereas escape rooms in which students can attempt to solve multiple puzzles simultaneously are more intricate.

Escapp has been designed on the basis of an extensive requirement elicitation [65], performed as a result of conducting several educational escape rooms for teaching computer science topics at UPM (e.g. [36]–[38]), as well as reviewing educational escape rooms experiences in other knowledge areas reported in the literature, which provided a comprehensive view of the distinctive characteristics that educational escape rooms in various fields have compared to other learning activities. The rest of this section describes Escapp's main features as well as how Escapp assists teachers in each of the different phases involved in the process of conducting an educational escape room.

A. FEATURES

1) STUDENT ENROLLMENT

In order for students to participate in an educational escape room orchestrated with Escapp, teachers need to first create a profile for the escape room in this web platform. With this aim, they need to provide some basic information that allows

students to correctly identify the escape room: the escape room title, a thumbnail picture, the course to which it belongs, a brief description, and its duration.

Since conducting an educational escape room in a single session can be an overwhelming task, especially for large courses, teachers may want to run different shifts of the same escape room. Escapp allows teachers to schedule educational escape rooms on different days and times. Each shift can take place in a specific location or be conducted remotely. Alternatively, teachers can also schedule self-paced shifts in which students can participate in the escape room at the time of their convenience without requiring teacher intervention, which is especially useful for remote educational escape rooms. In addition, teachers can establish a maximum number of students and/or teams that can participate in each shift, for example, to comply with space limitations or availability of devices in the case of in-class escape rooms. Although escape rooms in general, and educational escape rooms specifically, can be played individually, they are usually conceived as team activities. In this regard, Escapp allows teachers to specify the maximum number of members that can belong to the same team participating in an educational escape room.

Escapp provides a unique link for each escape room that students need to use in order to enroll. Two ways of sharing this link are provided to instructors: (1) by sharing the link as it is or (2) by using a QR code. Teachers may use either or both formats to share the educational escape room with their students in any way they want: via email or the preferred student-teacher communication channel, making the link available in the virtual learning environment used in the course, or projecting the QR code in the classroom. Once students receive the link or QR code, they need to sign up in Escapp in order to access the educational escape room. At this point, they must choose the shift that suits them better, among the ones available, in order to save a spot to participate in the activity. Once they have selected a shift, they may join an existing team or create their own. The constraints specified by the teacher are applied during this process to ensure that the maximum number of simultaneous participants and teams as well as the maximum number of team members in each team are not exceeded.

2) INSTRUCTIONS

It is important for students to get acquainted with all the instructions of the activity before participating: whether they can consult their course materials during the escape room, if they are allowed to talk to other teams, how to proceed if they get stuck during the activity, how it is going to be graded, etc. Furthermore, they need to know whether they need to prepare in any way beforehand, such as by having certain materials or supplies with them during the activity (headphones, pen and paper, a smartphone...), by installing a specific software tool or package on their computers, or by reviewing a specific lesson prior to participating. Teachers may provide all this information by using the WYSIWYG (What You See Is What You Get) web editor provided by

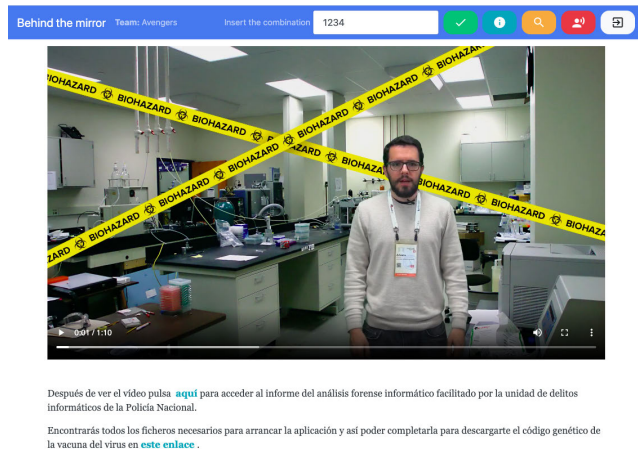


FIGURE 1. Screenshot of the team interface of an educational escape room.

Escapp for this purpose. Through this editor, they can include text, links and all sorts of multimedia files to elaborate the instructions. Students will be able to see these instructions once they enroll in the escape room.

3) ROLL CALL

Recording student attendance is of special relevance if an escape room is scheduled as a mandatory course activity or if it has an impact on students' grades. Teachers might choose how attendance is taken in their Escapp-based educational escape rooms by selecting one of the following three options: (1) manually (teachers need to take roll call and check in students one by one), (2) automatically considering present every student who accesses the escape room through Escapp while it is running, or (3) automatically considering present all those students who belong to a team for which at least one of its members accesses the escape room through Escapp before it ends. While the second approach is necessary for conducting remote educational escape rooms, the latter approach is particularly useful when teams participate using a single device, which is often the case in face-to-face educational escape rooms.

4) TEAM INTERFACE

Escapp provides each participating team of students with a team interface (see Fig. 1), which they can access while playing in order to view the content of the activity (at least part of it, since other content can be provided physically in face-to-face experiences), introduce their answers to the different puzzles, request hints, and consult whatever additional information the teacher wants them to see while they are playing.

The team interface includes content authored by the teacher (text, links, multimedia objects...), which is specific to each particular escape room, as well as a top bar with a series of buttons through which participating students can perform different actions that are common to all escape rooms. From left to right, these actions are:

- **Solving puzzles:** Students can enter the solution of the puzzle they are currently working on and check whether it is correct or not. The whole team will be notified of whether the answer is right or wrong (regardless of whether or not they share the same device). In this regard, it is worth mentioning that puzzles can be solved not only by using the team interface but also from external applications (see section III-A8). Details about the actions teachers need to perform in Escapp in order to define the escape room puzzles are provided in section III-A5.
- **Consulting escape room state:** Any time during the course of the activity, students can access a report containing the most relevant information regarding their progress toward completing the escape room. They can consult all the puzzles their team has solved, the solutions of these puzzles, the messages obtained after solving such puzzles, and the hints they obtained throughout the activity organized by puzzles and categories.
- **Requesting hints:** If the teacher has established that students are allowed to ask for hints during the escape room, the team interface will provide the selected mechanism to do so. The available mechanisms are discussed in section III-A6.
- **Accessing troubleshooting assistance:** Teachers may specify a link to a video conference room in order to provide troubleshooting assistance while students play. This option is especially useful in remote educational escape rooms in which no other communication channel is available between participants and supervisors.
- **Exiting:** Students may abandon the escape room and come back any time before it is over.

As mentioned, in addition to the actions described, students can view content related to the escape room. It is worth mentioning that not all the content of the escape room has to be provided by means of the team interface provided by Escapp, but rather it can be presented to the students through other physical or digital media (e.g. with physical envelopes hidden in the room or via web applications hosted outside Escapp). The content provided to students by using the Escapp team interface might include text, links to external resources (e.g. a newspaper clipping), and multimedia files (e.g. an introductory video or an audio recording). It can also include several gamification elements (which are explained in section III-A7). Teachers may compose this content and customize the disposition in which the different elements will be shown to students through a WYSIWYG editor provided by Escapp. Furthermore, teachers can also choose a theme (among 21 different options) in order to automatically set up a color scheme and a typography for the whole team interface. Lastly, it should be indicated that the teacher-authored content shown to a team through the team interface during an educational escape room may change as this team progresses in the activity. Escapp enables teachers to create different blocks of content and decide which ones will be shown to each team depending on the puzzles previously solved.

Regarding team collaboration, it should be indicated that when Escapp is used for conducting an educational escape room, its state is automatically synchronized among all team members. Thus, the content of the team interface shown to each of the members of one team is the same at all times. For instance, if a student solves a puzzle or obtains a hint, the team interface of all the team members is updated to reflect these accomplishments. Regarding team communication, it should be clarified that the current version of Escapp does not provide real-time video or audio communication among participants. In face-to-face experiences, teammates are expected to communicate in person, whereas in remote experiences they are expected to use external applications that enable real-time communication such as Zoom, Google Meet, Microsoft Teams, Skype or Discord.

5) PUZZLES

In order to succeed in one educational escape room conducted with Escapp, participating students need to submit the solution to all the puzzles through Escapp (either through the team interface or through external applications as explained in section III-A8). In this regard, it should be taken into account that the educational escape rooms conducted with Escapp must be linear (i.e. a puzzle must be solved before advancing to the next one). Therefore, once a team submits a solution to a puzzle, Escapp will check the solution to determine whether it is right or wrong and, if it is right, students will go on to the next puzzle, whereas if it is wrong, they will need to keep trying as many times as they want until they succeed. All the actions performed by a team member are made on behalf of the entire team, so only one member of the team needs to provide the right answer to a puzzle in order to advance. To force students to solve the puzzles in the right order and to check the correctness of the solutions they submit, teachers must specify the sequence in which puzzles are arranged as well as the correct answer for each one of them. In addition, teachers may also specify a message to be shown to the students when they get the answer wrong, and another one for when they get it right. A screenshot of the interface in which teachers set up the puzzle information is shown in Fig. 2.

6) HINTS

It is necessary to provide students with timely help during educational escape rooms since they often get stuck when solving a puzzle, be it because they lack the necessary field-specific knowledge or skills, or due to other reasons such as difficulties in understanding game mechanics or the need for a clue or object that they have not found or have overlooked. In order to address this need, Escapp allows teachers to define specific hints for each of the puzzles of an educational escape room. Since Escapp keeps track of students' progress during the activity, it is possible to ensure that the hints provided by Escapp when students ask for one are related to the puzzle at which they are stuck, and therefore they are potentially helpful to them. Teachers can specify

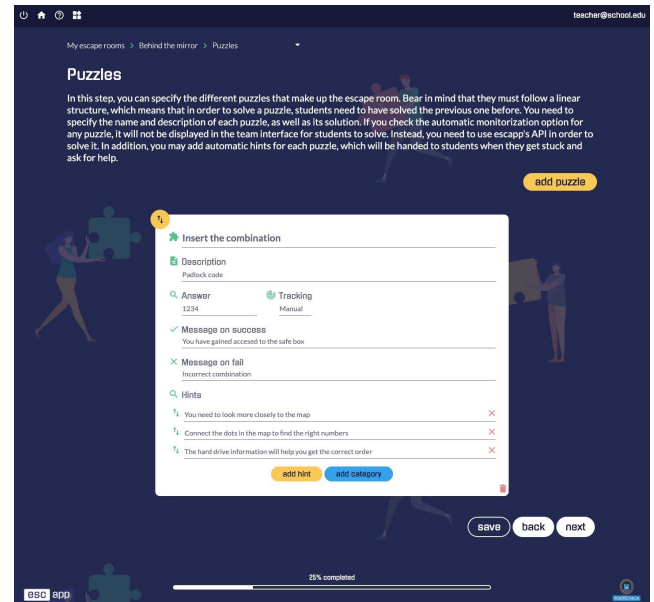


FIGURE 2. Screenshot of the step for creating puzzles and hints in the teacher form.

multiple hints for each puzzle in a specific order so that each hint will be handed out to a team once all the previous hints have been obtained. This feature allows teachers to first provide vague hints and progressively get into more detail. This is useful to avoid making it too easy to figure out the answer of the puzzle with just one hint, requiring students to request a number of hints proportional to the amount of help needed. In self-paced escape rooms without teacher supervision, it can be convenient to give away the solution of each puzzle as its last hint, to prevent students from becoming frustrated and abandoning the escape room. If more granularity is required, hints can be grouped into categories that represent different parts or aspects of a puzzle. If more than one category is available for a given puzzle, at the moment of requesting a hint, students will be able to select the hint category with which they need assistance. Each category can have several hints as well, which will also be handed out in the order set by the teacher. For instance, this feature could be used in a puzzle that requires students to find different symbols in order to give them the chance to choose the symbol for which they wish to receive help.

Escapp provides two ways in which students can get hints once requested: for free or by passing a quiz. If students are required to pass a quiz in order to obtain a hint during an escape room, teachers must provide a pool of questions by uploading a file in Moodle XML format [66], specify how many questions (randomly selected from the pool provided) will be shown to students on each quiz attempt, and indicate how many questions they need to answer right in order to obtain a hint. Moreover, to prevent students from requesting help all the time and solving the escape room without dedicating the appropriate time to face the puzzles, teachers may establish a minimum time interval between

hints. Thus, when students receive a hint they have to wait before they can ask for more. Moreover, teachers may also establish an overall hint limit (i.e. the maximum number of hints that a team can obtain), which students should be aware of from the beginning. In addition to the prior hint constraints, Escapp offers the option to tell students to ask the teachers for a hint when there are no hints available for a puzzle (or category) with which they need help. Notwithstanding, it should be noted that this option is not feasible for use in self-paced shifts in which there are no teachers supervising the activity. By combining the two ways of handing out hints, the time and quantity constraints, and the teacher-provided hints option, Escapp supports a total of 16 different strategies for managing hints during an educational escape room. Furthermore, teachers can choose not to allow students to request hints during an educational escape room.

The team interface shown to students during an escape room will adapt to the hint strategy set by the teacher. Thereby, if hints are given out freely, students just need to click the hint button made available to them on the team interface in order to obtain one. On the other hand, if the teacher has selected the quiz mechanism for giving out hints, a quiz with the number of questions and behavior specified by the teacher will be presented to students. In this case, only by passing the quiz will students obtain a hint. If a team cannot request hints at a certain moment, be it because not enough time has passed since the last hint they obtained, because the maximum number of hints that a team is allowed to obtain has been reached, or because there are no more hints available for the puzzle they are working on, the team interface will inform students of the exact reason why they cannot request more hints. Lastly, it should be mentioned that if a puzzle has hints belonging to multiple categories, students will be able to choose with which one of these categories they need help every time they ask for a hint.

7) GAMIFICATION ELEMENTS

It is common in gamified learning activities to use gamification elements in order to foster competition and a playful atmosphere. In this regard, Escapp allows teachers to show gamification elements to all participants of the educational escape room by including them in the team interface. In face-to-face escape rooms, some of these gamification elements can also be shown to all participants through a single interface intended to be projected in the classroom (see III-A9 for details). The gamification elements supported by the current version of Escapp are the following:

- **Leaderboard:** A leaderboard showing the names and current progress (number of puzzles solved) of the participating teams helps trigger competition among students and contributes to the feeling of tension that the escape room aims to create. The leaderboard is automatically updated every time a team solves a new puzzle. The more puzzles a team solves, the higher it will be in the

leaderboard. If two teams have solved the same number of puzzles, the one that took less time will be ahead. Whenever a team solves all the puzzles in the escape room, the completion time is shown in the leaderboard as well.

- **Countdown:** The countdown is a crucial part of any escape room to let participants know the time they have left to complete the activity and to create the sense of urgency that is so distinctive of escape rooms.
- **Progress bar:** By showing a progress bar indicating the percentage of puzzles solved by their team, students can get a feel of how far along they are in the escape room. Since this information is different for each team, it can only be shown in the team interface.
- **Confetti:** Whenever a team solves all the puzzles of the escape room and finishes the activity, the team interface gets filled with confetti. This resource is employed to let students know they have succeeded at the escape room.

8) WEB API FOR EXTERNAL APPLICATIONS

Instead of allowing students to use the designated area of the team interface to insert the puzzles' answers, teachers and escape room designers can take advantage of Escapp's web API to connect their own digital escape room puzzles with Escapp in order to enable students to solve puzzles outside the Escapp platform. The Escapp web API provides external applications with an endpoint for verifying the solution and solving each of the puzzles in an escape room registered in Escapp. This feature allows teachers to provide part of the content of an educational escape room conducted by Escapp through external applications. If a puzzle is intended to be solved outside Escapp from an external application, teachers have the option to hide, for this puzzle, the team interface area reserved to write puzzles' answers.

In order to facilitate puzzle developers make use of the Escapp API, Escapp provides a client library for web-based puzzles. This library takes care of authenticating students against Escapp, submitting each attempt to solve a puzzle, and showing relevant events to students in real-time during the escape room, such as leapfrogging in the leaderboard, time remaining notices, and a notification each time a new puzzle is solved or a new hint is obtained by anyone in the team. In addition, the library allows synchronizing the escape room state between the applications run by all members of a team, so they can all be at the same point at all times. The Escapp client library can even allow synchronizing the escape room state when different web applications are used to represent different puzzles, greatly opening up a range of possibilities for teachers, who can put together several digital puzzles of different natures in order to assemble an educational escape room. It should also be remarked that the escape room state is not only synchronized among applications using the Escapp client library, but also with the team interface provided by the Escapp platform.

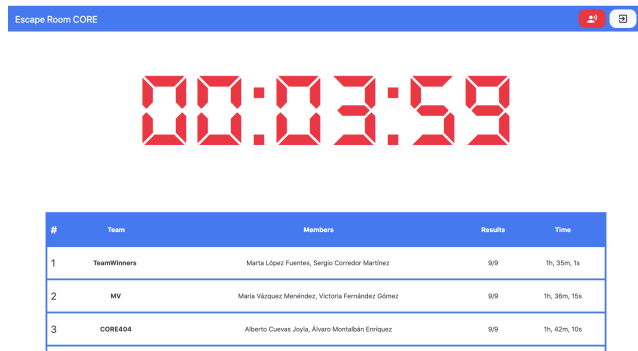


FIGURE 3. Screenshot of the leaderboard and countdown in the class interface.

9) CLASS INTERFACE

In addition to an interface for teams, the platform allows teachers to configure a screen that they can project in the classroom while a face-to-face educational escape room takes place. Like the team interface, the class interface may include text, links and/or multimedia files (such as the introductory video of the escape room) that can be added through a WYSIWYG editor. It can also include some of the aforementioned gamification elements (leaderboard and/or countdown, as shown in Fig. 3). Teachers might select the content disposition and a fitting theme just like in the team interface.

10) LEARNING ANALYTICS

During the course of an educational escape room, Escapp automatically records the major student interactions with the platform. In particular, the following data are collected: the students and teams that access an educational escape room, the puzzles solved by each team, the hints requested and received by each team (if a quiz-based hint approach is used, the number of failed and successful attempts are also recorded), and the time required by each team to solve each puzzle and to complete the escape room (if applicable). It is necessary for the teacher to have access to all the information available throughout the escape room to gain insights into what is happening during the activity and act accordingly. For instance, they might want to identify teams that are struggling to provide them with additional help. For this purpose, Escapp presents all the information gathered at run-time in a way that is easy to understand for teachers through a learning analytics dashboard.

The learning analytics dashboard is not only targeted at monitoring the escape room while students are playing. Through this dashboard, teachers are capable of analyzing the results after the activity is over and act upon them. Teachers can filter the information by each specific shift or perform an overall analysis for the whole educational escape room. A lot of useful information can be extracted from students' interaction data upon completion of an educational escape room. For instance, teachers can find out at which puzzles students get stuck more often, so they can dedicate more time in class

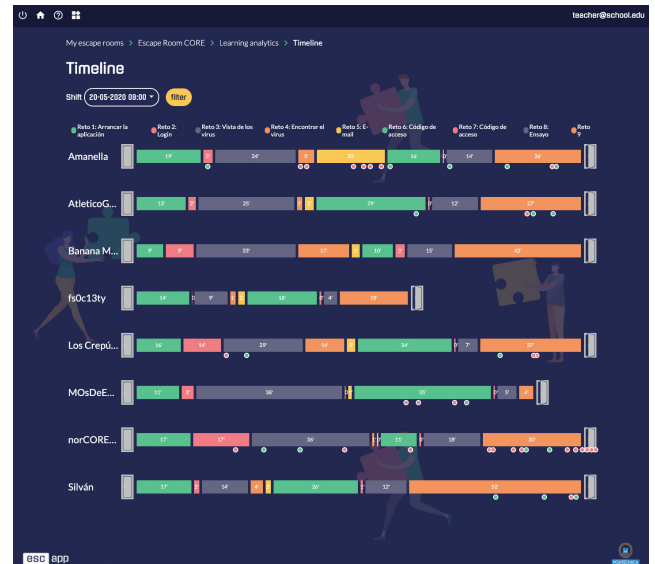


FIGURE 4. Screenshot of the timeline section of the learning analytics dashboard.

to review the concepts covered in those puzzles. In case the learning analytics visualizations are not enough for a specific analysis, teachers can download the data as CSV (Comma Separated Values) files to analyze them using the third-party software of their choice. The information presented by the learning analytics dashboard is the following:

- **Summary of the escape room data:** This information provides a quick overview of the results of the activity. It includes the number of participants, the best completion time, the average team size, the percentage of teams that succeeded, the number of teams that passed each puzzle, and the number of teams that obtained each hint.
- **Leaderboard:** It displays all the teams ordered by their performance in the escape room along with the time they took to finish it (if applicable). This visualization is extremely useful to identify top teams and lagging ones, and to assess the differences between teams in terms of performance.
- **Progress graph:** It shows, for each team, the puzzles they have solved and the moment of the escape room in which each of them was accomplished. This information can be used to compare the progress among different teams and identify patterns in their behavior.
- **Timeline:** This visualization shows a timeline with all the data collected for each team, including the puzzles solved, the time spent in each puzzle, the hints obtained, and the hint requests that were not successful if using the quiz approach, as shown in Fig. 4. Since this is the most complete visualization, it allows teachers to get a very close idea of what is going on or what went on during the escape room. For instance, they can find out how long a team is taking or took to solve a puzzle or whether a certain hint was useful (if students solved the puzzle shortly after seeing the hint).

- **Histogram:** It represents the frequency distribution of the times each puzzle was solved, allowing to identify at which point in the escape room students usually work on a given puzzle, for how long they work on it, etc. This may be useful to determine the average time taken by students to solve each puzzle and take it into consideration in subsequent re-runs of the escape room to prevent lagging teams to exceed this time by a long way by scheduling timely interventions.
- **Hint chart:** It displays the number of hints obtained by each team, allowing teachers to quickly get a general idea of whether students resorted to hints when they needed help during the activity. When following the quiz approach for hints, this visualization also shows the successful and failed attempts to obtain a hint, which can be an indicator of how well-acquainted students were with the learning content covered in the questions.

11) GRADING

Teachers may configure the grading scheme of an educational escape room by selecting the different aspects to be taken into account for calculating students' grades and assigning weights to each one of them. The aspects that can be considered in order to calculate students' grades are the following: attendance, puzzle completion (different puzzles may have different weights), and the number of hints requested and obtained (adding or subtracting points for obtaining a hint or for failing to obtain one if using the quiz approach). By taking into account all of these variables when grading students, teachers can provide them with a grade proportional to their effort and performance rather than just a boolean outcome (whether they successfully completed the activity or not). After the educational escape room is over, teachers can view the grades calculated for each student according to the pre-defined grading scheme. Teachers can perform modifications to this scheme even after the escape room has taken place. The grades calculated can be downloaded as a CSV file, allowing to easily import them to the course virtual learning environment.

B. PHASES

Four phases have been identified in the process of conducting an educational escape room by using Escapp: escape room profile creation, distribution to students, execution and evaluation. The features that Escapp has to offer in the scope of each of these phases are described below.

1) ESCAPE ROOM PROFILE CREATION

The first step that teachers need to perform in order to conduct an educational escape room through Escapp is creating a profile in the platform that includes all the information needed to run the activity. It should be pointed out that this phase is supposed to be carried out by teachers after (or while) designing and building the educational escape room itself (i.e. all the puzzles and resources involved in the activity), but prior to its conduction. First of all, teachers need to register in

the Escapp web platform with the appropriate role and log in. Once logged in, teachers can see all the escape room profiles they have created in the past and proceed to create a new one. In order to create an educational escape room profile in the platform, teachers need to fill in an eight-step form in which they need to specify all the characteristics of the escape room: basic information, shift configuration, puzzles and hints, hint management strategy, team interface content and layout, class interface content and layout, instructions, and grading scheme.

2) DISTRIBUTION TO STUDENTS

The distribution phase encompasses the period from when the teacher has finished creating the educational escape room profile in the Escapp platform up to the moment when students can participate in the activity. In this phase, teachers may share the link or QR code generated by Escapp for the escape room with their students. Through either of these ways, students must sign up in Escapp and enroll in the escape room. First, they need to choose one of the shifts available to participate in the escape room. Then, they must join an existing team or create one of their own. Once they are enrolled, they can read the initial instructions of the activity provided by the teacher.

3) EXECUTION

The execution phase of an educational escape room encompasses all the actions that take place when students actually participate in the escape room. In order to participate, a student first needs to log in to Escapp and access the educational escape room profile in the web portal. Even though escape room shifts have a set schedule, they have to be initiated manually in order to officially give start to the escape room. In the case of self-paced shifts, it is the students themselves who initiate the escape room whenever they please while in the other shifts it is the teachers who have the responsibility of initiating them. Once an escape room starts, students may access the team interface on their computers. If it is an in-class escape room, the teacher can project the class interface for everyone to see. In this case, it is also common to manually take attendance to keep tabs on who is participating. Throughout the course of the educational escape room, students explore the provided content and clues, solve the different puzzles, and request hints when they get stuck. In remote educational escape rooms, Escapp also allows teachers to provide students with a link to a video conference room for troubleshooting assistance. Lastly, teachers may use the learning analytics dashboard to monitor the teams so as to gain insights into what is happening during the activity and act accordingly.

4) EVALUATION

The evaluation phase of the escape room is the last one and takes place once all students have participated in the activity. This phase covers both student grading and retrospective of the escape room experience. On the one hand, teachers can

TABLE 1. Characteristics of the case studies.

	CS1	CS2	CS3
Course topic	Front-end development	Back-end web development	Software engineering fundamentals
Total number of escape room participants	97	136	180
Student questionnaire sample	82	129	162
Escape room characteristics			
Learning objectives	Develop front-end applications using React.js, Redux and React Native	Develop full-stack applications using Node.js and Express	Understand and interpret software modeling diagrams
Final goal	Defuse an explosive device	Recover the genetic code of a vaccine	Generate a vaccine for a deadly virus
Format	Face-to-face	Remote	Remote
Duration	2 hours	2 hours	2 hours
Team size	Pairs	Pairs	1-6 people (generally 4-6)
Hint strategy	5-question quiz	5-question quiz limited to 4 min. between hints	5-question quiz limited to 5 min. between hints
Puzzle types	Physical and computer-based puzzles	Computer-based puzzles	Computer-based puzzles
Used Escapp client library	No (only Escapp API)	Yes	Yes

calculate the students' grades using Escapp in an automatic way, export these grades to a CSV file, and upload them to the virtual learning environment of the course, integrating them with the grades of the rest of the assessment activities. On the other hand, teachers can perform a post-analysis of the escape room through the Escapp's learning analytics dashboard as well as export the data collected by Escapp to analyze them with external software tools.

IV. EVALUATION METHODOLOGY

A total of three independent case studies were conducted in order to empirically evaluate the usefulness of Escapp for conducting educational escape rooms. In each case study, Escapp was used to conduct a different educational escape room in a different large-enrollment university course. Table 1 summarizes the main characteristics of these three case studies. As can be seen in this table, in case study 1 (hereafter CS1), a face-to-face educational escape room was conducted in a front-end development course; in case study 2 (CS2), a remote educational escape room was conducted in a back-end web development course, and in case study 3 (CS3), another remote educational escape room was conducted in a software engineering fundamentals course.

The escape room examined in CS1 was conducted in a computer lab in two different scheduled shifts. In this escape

room, students worked mostly in pairs (although one team had three members) and had to apply the programming knowledge acquired throughout the course to complete a client-side web application with the final aim of deactivating an explosive device threatening to blow up the whole school. A previous edition of this escape room is described in [36].

The escape room examined in CS2 was conducted remotely and allowed students to enroll in a scheduled shift or to participate at the time of their convenience through a self-paced shift. In this escape room, students were grouped in pairs (although a few of them worked individually) and provided with a backup of the hard drive of a deceased scientist, which contained different files and folders, including a web application that students had to understand and modify in order to recover the genetic code of a vaccine the scientist had discovered. A previous edition of a face-to-face version of this escape room has been described in [37].

The escape room examined in CS3 was also conducted remotely allowing students to participate through several scheduled shifts as well as through a self-paced shift. In this case, most students participated in teams of 4-6 members, although some of them participated in small teams of 3 members, in pairs, or even alone. The overarching goal of the escape room was to generate the vaccine for a deadly virus by using a web application foreign to the participants. In this application, students found different descriptions of use cases and software modeling diagrams (sometimes incomplete, altered or disordered), which they had to interpret correctly in order to operate the web application and succeed at the escape room. A detailed description of this remote educational escape room can be found in [38].

All three educational escape rooms were conducted by using the Escapp platform presented in this work. In these escape rooms, part of the content was provided to students directly through Escapp's team interface, while other content was provided physically (only in CS1) and via links to external ad hoc software applications. These applications were built by the faculty staff and communicated with Escapp through the API provided by the platform. In this regard, it should be indicated that the software applications used in the escape rooms conducted in CS2 and CS3 made use of the Escapp client library previously described to keep track of students' progress, to synchronize the escape room state among team members, and to display relevant events to students during the activity. Moreover, all three escape rooms used Escapp's quiz-based approach for handing out hints to students whenever they got stuck, although the escape rooms in CS2 and CS3 only allowed students to obtain one hint every four and five minutes respectively, whereas the one in CS1 did not impose any time constraints and allowed students to request hints directly to teachers when no more automatic hints were available. The escape rooms examined in CS2 and CS3 included a live leaderboard to foster competition, in which students could see the progress of each of the competing teams.

The automatic tracking feature of the Escapp platform allowed to record students' attendance, every puzzle solved by each team, and every attempt to obtain a hint (whether successful or not). The total number of interactions recorded by Escapp during each educational escape room was calculated to evaluate the total load to which Escapp was subjected. In order to gain insights on the peak workloads that the platform had to endure, the number of students' interactions that took place within a minute (i.e. practically simultaneously if they were to be handled manually by a single person) was calculated as well. In addition to the maximum number of simultaneous interactions that were actually recorded, the maximum number of simultaneous interactions that would have been recorded in the hypothetical case in which all students had participated in the escape rooms at the same time in a single shift was also computed.

In order to collect students' opinions on the use of the Escapp platform, the instrument used was an ad hoc questionnaire. This questionnaire had to be developed expressly for this evaluation since no prior work in the literature has assessed software tools specifically designed for conducting educational escape rooms before. The questionnaire developed by the authors included some initial demographic questions, a set of closed-ended questions addressing students' general perceptions and acceptance of Escapp and their opinions of the educational escape rooms, and a list of statements with which they needed to agree or disagree using a 5-point Likert scale. At the end of the questionnaire, there was a space in which students could leave suggestions, complaints, and other comments. Students completed the questionnaire after each educational escape room took place. Students' responses were analyzed using descriptive statistics.

The sample consists of 413 participants: 97 in CS1, 136 in CS2, and 180 in CS3. Out of the 413 overall participants, 373 completed the questionnaire: 82 students (66 men, 15 women and 1 non-specified) from CS1, 129 students (95 men, 32 women and 2 non-specified) from CS2, and 162 students (132 men, 29 women and 1 non-specified) from CS3. All participants' ages ranged from 18 to 42, being 21.8 (SD = 1.2) the mean age in CS1, 21.3 (SD = 2.2) in CS2, and 20.7 (SD = 2.2) in CS3. Almost half the students had participated in an escape room before (58.5% in CS1, 55.0% in CS2 and 40.7% in CS3). However, considerably fewer of them had previously participated in an educational escape room (28.0% in CS1, 18.6% in CS2 and 2.5% in CS3). Regardless of whether they had participated in an escape room before, students agreed with the fact that they liked playing games by 4.4 points on average (SD = 0.9), on a scale of 1 to 5 (CS1: M = 4.4, SD = 0.8; CS2: M = 4.3, SD = 1.0; CS3: M = 4.6, SD = 0.7).

V. RESULTS AND DISCUSSION

A. DATA AUTOMATICALLY GATHERED BY ESCAPP

Table 2 summarizes the main results derived from the data automatically collected by Escapp during the educational escape rooms analyzed in the three case studies including,

TABLE 2. Escape room data automatically gathered by Escapp.

	CS1	CS2	CS3
Total number of counted escape room participants	97	136	180
Total number of counted escape room teams	48	76	45
Total number of hints delivered	203	318	118
Maximum hints delivered within a min.	6	3	2
Maximum hints delivered within a min. (single shift)	9	8	4
Total quiz attempts handled	476	1113	179
Maximum quiz attempts handled within a min.	12	8	3
Maximum quiz attempts handled within a min. (single shift)	14	17	5
Total tracked puzzles solved	169	590	296
Maximum tracked puzzles solved within a min.	7	6	4
Maximum tracked puzzles solved within a min. (single shift)	7	16	10
Total number of recorded interactions	790	1915	700
Maximum recorded interactions within a min.	14	8	4
Maximum recorded interactions within a min. (single shift)	18	24	12

for each item tracked by Escapp, the total number of interactions recorded for each escape room, the maximum number of these interactions that took place within a minute, and the maximum number of these interactions that would have taken place within a minute if each escape room had been conducted in a single shift.

Overall, Escapp tracked the attendance of a total of 413 participants distributed in 169 teams: 97 participants (48 teams) in CS1, 136 participants (76 teams) in CS2, and 180 participants (45 teams) in CS3. A total of 790 interactions were recorded in CS1, 1915 in CS2, and 700 in CS3. Although the three escape rooms conducted had the same duration, the learning context, the content, the difficulty and number of puzzles, the number of participants and teams, and the average number of team members varied from one another, resulting into notable differences among the number of interactions recorded for each case study. Despite the differences found, in view of the results obtained, it becomes clear that the number of interactions that need to be handled when conducting these educational escape rooms is extremely high, which constitutes indisputable evidence of the immense effort it would entail for teachers if they were to handle them manually, not to mention the impossibility of doing so in the case of remote educational escape rooms.

In order to analyze the peak workloads to which Escapp was subjected, the maximum number of simultaneous interactions (within a one-minute interval) are presented, which amounted to 14 in CS1, 8 in CS2, and 4 in CS3. In this regard, it should be taken into account that several shifts were conducted for each escape room and hence the student interactions recorded by Escapp in each escape room took place distributed among the duration of different shifts. It should also be taken into account that the number of shifts conducted and the maximum number of participants in the same shift were different for each escape room, which notably

TABLE 3. Results of the student questionnaire.

Question	CS1			CS2			CS3			Total		
	N	M	SD	N	M	SD	N	M	SD	N	M	SD
What is your overall opinion on the Escapp platform?	82	4.4	0.6	128	4.5	0.6	162	4.2	0.9	372	4.3	0.8
Escapp is easy to use	82	4.2	0.8	129	4.4	0.9	162	4.5	0.7	373	4.4	0.8
Escapp has an attractive graphical user interface	82	4.2	0.8	129	4.3	0.9	162	4.4	0.7	373	4.4	0.8
Escapp has been useful to enroll in the escape room and join a team	82	4.2	0.8	129	4.5	1.0	162	4.4	0.8	373	4.4	0.9
Escapp has been useful to manage my participation in the escape room	82	4.2	0.8	129	4.3	1.1	162	4.4	0.8	373	4.3	0.9
I would rather participate in an escape room conducted by Escapp than in a similar activity that lacks digital support	82	4.1	0.8	129	3.8	1.4	162	3.9	1.0	373	3.9	1.2
The information provided by Escapp (materials, schedule, instructions, countdown...) was adequate and sufficient at all times	82	4.1	0.8	129	4.2	1.0	162	4.4	0.8	373	4.3	0.9
The mechanism for requesting hints during the escape room provided by Escapp works properly	82	4.2	0.9	129	4.1	1.3	162	4.3	0.9	373	4.2	1.1
The leaderboard provided by Escapp motivates me	-	.	.	129	4.1	1.3	162	4.3	0.9	291	4.2	1.1
The Escapp client library was useful	-	-	-	125	3.9	0.9	162	4.3	0.8	287	4.2	0.8
The Escapp client library was too intrusive	-	-	-	125	2.7	1.1	162	2.4	1.2	287	2.5	1.2
What is your overall opinion on the escape room?	82	4.4	0.7	129	4.3	0.8	162	4.6	0.6	373	4.4	0.7
I agree that the escape room must be a graded activity	82	3.6	1.2	129	3.8	1.5	162	4.2	1.1	373	4.0	1.3

affected the maximum interactions recorded within a minute. Moreover, it should be clarified that interactions for recording student attendance were not taken into account for calculating the peak workloads, since only interactions initiated by students were considered.

In order to provide further evidence of the magnitude of the number of student-initiated interactions that need to be handled during educational escape rooms, the table also shows the maximum number of simultaneous interactions (within a one-minute interval) that would have been recorded in the hypothetical case in which the educational escape rooms had been conducted in a single shift where all students had participated at once. In this case, the number of simultaneous interactions would have been even more unmanageable, amounting to 18 in CS1, 24 in CS2, and 12 in CS3. Naturally, as the number of simultaneous players increases, so does the number of simultaneous interactions. Overall, the figures obtained provide a clear view of the peak workloads that need to be handled to effectively conduct educational escape rooms. These peak workloads would have been practically impossible to attend by teachers manually and thus, if the examined educational escape rooms had been conducted without using a specialized software system such as Escapp, the peak workloads found would have probably led to students getting frustrated and/or disengaged.

In sum, the analysis of the data collected shows that the use of Escapp allowed to scale up face-to-face and remote educational escape rooms for a large number of students by automating the process of taking attendance, delivering content, checking the solutions to the different puzzles, and handing out hints.

B. RESULTS OF THE STUDENT QUESTIONNAIRE

Table 3 shows the results of the ad hoc evaluation questionnaire administered to students after each of the three

escape rooms, including, for each question, the mean (M), the standard deviation (SD), and the number of answers (N).

Firstly, the results show that students had a very positive opinion of the three educational escape rooms ($M = 4.4$, $SD = 0.7$) conducted through Escapp. This was an expected outcome given the promising results obtained in previous editions of these escape rooms [36], [37]. This first finding shows that Escapp allows teachers to conduct educational escape rooms that have the potential to achieve high student acceptance. Moreover, students agreed that the escape room must be a graded activity ($M = 4.0$, $SD = 1.3$), which underlines the need for the grading feature provided by Escapp.

Regarding students' general perception of Escapp, they had a very positive overall opinion ($M = 4.3$, $SD = 0.8$), and they stated that it is easy to use ($M = 4.4$, $SD = 0.8$) and that it has an attractive graphical user interface ($M = 4.4$, $SD = 0.8$). These two aspects bring to light the fact that Escapp provides an enjoyable user experience for students while participating in educational escape rooms, which is one of the central objectives of the Escapp platform.

In terms of usefulness, students reported that Escapp was useful to register in the escape room and join a team ($M = 4.4$, $SD = 0.9$), as well as to manage their participation in the escape room ($M = 4.3$, $SD = 0.9$). Thus, Escapp was helpful for students throughout the whole process of participating in the escape room. Moreover, respondents stated they would rather participate in an escape room conducted by Escapp than in a similar activity that lacks any digital support ($M = 3.9$, $SD = 1.2$), providing further proof that Escapp's features have been useful for students and that they did not hinder the course of the activity but rather made it easier and more enjoyable.

According to students, the information provided by Escapp was adequate and sufficient at all times ($M = 4.3$, $SD = 0.9$). This information includes the instructions shown

to students prior to participating as well as all the information displayed while the escape room took place: the countdown, the leaderboard, the hints, the progress bar, and the content of the escape room itself provided by means of the team interface.

Furthermore, the mechanism for requesting hints during the escape rooms provided by Escapp, consisting in answering a quiz with five questions, worked properly in all cases according to students ($M = 4.2$, $SD = 1.1$). This is further supported by the fact that teams obtained on average 4.2 hints in CS1, 4.1 hints in CS2, and 2.7 hints in CS3, according to the data collected by Escapp. These results also provide evidence that Escapp succeeded in helping students when they got stuck when trying to solve escape room puzzles, both in face-to-face and remote escape rooms.

On another note, students of CS2 and CS3 found the leaderboard in real-time to be motivating ($M = 4.2$, $SD = 1.1$), which was the main reason for including it in the first place. Leaderboards have been used before in escape rooms reported in the literature such as [67], an orientation activity for engineering students, and [10], a simulation teaching strategy in nursing. However, the leaderboards used in these experiences were updated only when students completed the activity, instead of each time a team made some progress in the escape room, failing to promote competition among the different teams. To the knowledge of the authors, the use of real-time leaderboards in educational escape rooms has not been reported before in the literature, making the findings on their ability to further foster student motivation in these activities another valuable contribution of this work.

Lastly, students of CS2 and CS3 were asked to rate different aspects of the Escapp client library, which was used by the ad hoc software applications used during the escape rooms to provide students with part of the content in order to communicate with Escapp, as well as to synchronize students' progress within a team and to notify them of relevant events. Students thought the Escapp client library was useful ($M = 4.2$, $SD = 0.8$), which was an expected result since it displayed relevant information to students without a need to switch back and forth between the software applications and the team interface and, most importantly, it allowed them to solve some escape room puzzles together remotely since the client library took care of synchronizing teams' progress. Students also slightly disagreed with the fact it was too intrusive ($M = 2.5$, $SD = 1.2$). This means that they did not find the number of notifications displayed by the library to be excessive and that these notifications did not hinder their participation in the escape room.

At the end of the questionnaire, there was a space for comments, suggestions, and complaints. Students mainly commented on how much they enjoyed the educational escape rooms and thanked the teachers for making the effort of organizing these activities, which confirms the fact that Escapp allows to conduct highly engaging educational escape rooms. Some of the students made some suggestions regarding the design of the escape room itself. For instance, a few

participants of CS2 said they would have preferred participating in larger teams rather than in pairs. Others wished they got feedback after answering the quiz questions for obtaining hints or to be able to request hints continuously rather than every five minutes. It should be noted that the few aspects of the educational escape room that students suggested to change corresponded to decisions made by the teaching staff on purpose; they were not a result of any limitation imposed by Escapp. In fact, everything students suggested would be feasible with the current features that the Escapp platform offers. Lastly, a few students merely praised Escapp's graphical appearance, corroborating the results obtained in the corresponding item in the questionnaire.

VI. CONCLUSION

This article presents Escapp, an open-source web platform for conducting face-to-face and remote computer-based educational escape rooms, which provides teachers with all the features necessary for conducting this novel type of learning activity. Specifically, Escapp is capable of assisting instructors with student registration, team formation, control of the execution of the activity (management of resources, narrative events, and gamification elements), progress monitoring, hint management, and grading. The results of this article show that Escapp can be used to conduct effective and highly engaging educational escape rooms, both in face-to-face educational settings as well as in distance online learning settings. These results also provide evidence of the high number of student interactions that should be handled during educational escape rooms and the irrefutable need for teachers to use software systems like Escapp to effectively handle these interactions and conduct educational escape rooms.

Taking into account that conducting educational escape rooms is a complex and laborious task for teachers that could be eased by using appropriate tools, and that no studies have previously reported on the use or development of any software tool for conducting face-to-face and remote educational escape rooms, this article makes an important contribution to help overcome one of the main barriers hampering the widespread use and uptake of educational escape rooms by presenting, for the first time, a software tool that empowers teachers to conduct face-to-face and remote educational escape rooms in an easy and efficient way. According to [68], replacing rudimentary puzzles (such as locks and keys) with computer-based systems is the basis for creating third-generation escape rooms and, going one step further, automating the hint delivery process and monitoring the progress of players are characteristics that one would expect from fourth-generation escape rooms. Therefore, Escapp allows teachers not only to carry out educational escape rooms and join this growing trend, but to position themselves at the forefront of this teaching practice by developing new generation escape rooms.

Since the evaluation of Escapp presented in this work only addressed students' perceptions and not teachers' perceptions, the most immediate future work would be to conduct

an evaluation to examine perceptions of teachers and escape room designers toward the use of Escapp to conduct educational escape rooms. Furthermore, it would be of interest to validate Escapp in educational escape rooms conducted in different educational contexts, in courses of different areas of knowledge, in different educational levels, with different student profiles, or in different types of courses such as MOOCs. Lastly, another interesting future line of work would be to develop resources and software tools to ease the building of both physical and digital escape room puzzles. This way, educators would have tools to aid them not only in the process of conducting an educational escape room, but also during the design and building stages.

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