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Special Issue on

Educational Escape Rooms (EERs)

Guest Editor

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Special issue on Educational Escape Rooms (EERs)

Edited by Panagiotis Fotaris, University of Brighton, UK

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Guest Editor

Dr. Panagiotis Fotaris is a Principal Lecturer in Game Design at the University of Brighton, UK with expertise spanning computing, digital media, and user experience. He combines a deep understanding of pedagogical, social, and cultural factors with a passion for innovative learning technologies. His research focuses on harnessing the pedagogical potential of educational escape rooms, video games, and generative AI to transform teaching and learning practices.

Low-Threshold Digital Educational Escape Rooms Based on 360VR and Web-Based Forms

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Abstract: Escape rooms are an established game genre that has become popular in educational contexts in recent years. Digital escape rooms are variations, which use digital environments and may be played by participants not present on site. Compared to physical escape rooms, digital escape rooms are characterised by lower implementation and application efforts and at the same time by reduced intensity of the experiences. There is little evidence to date as to whether these low-threshold escape rooms are nevertheless sufficiently effective for learning. In this evaluation study, a learning activity based on a digital educational escape room (DEER) that uses the 360°-based spatial visualization (360VR) of a waterworks and a web-based form – contributing guidance and the escape room-specific challenges – is analysed. In the learning activity, students of environmental engineering study programs are asked to explore the 360VR-based waterworks guided by the instructions and challenges in the web-based form. Quantitative results of the study on learning outcomes and variables relevant to learning, such as emotion, motivation, and usability (N=73) are reported. The evaluation is supported by the qualitative results of guided interviews. Remarkably, some participants would have preferred to explore the 360VR environment without the guidance provided by the web-based form. Overall, the results show the learning effectiveness of the DEER, the efficacy of the web-based form as a guidance instrument, and values of learning-relevant variables that are conducive to learning. The DEER also achieved a high level of acceptance among students. Due to the low effort required for the creation of the DEER by lecturers and for application on the part of students, the presented combination of 360VR and web-based forms can be seen as a powerful low-threshold learning tool that enriches teaching.

Keywords: 360-degree, Virtual field trip, Virtual reality, Higher education, Motivation, Field trip, 360VR

1. Introduction

Escape rooms are described as puzzle games played with a time limit in a locked room of the real world by a team (Hall, 2021). The challenge to escape a physically locked room in which puzzles must be overcome under time pressure in a group and within a narrative creates highly immersive experiences (Anton and Pakhalov, 2022) that encourage many escape room visitors to repeat such experiences and that have led to strong growth in the number of escape room facilities in recent years (Spira, 2020). Like many games, escape rooms are also applicable in education (Ratan and Ritterfeld, 2009). While escape rooms were originally tied to a physical setting, various digital variants have emerged that can be played entirely online (Makri, Vlachopoulos and Martina 2021). The online playing of digital escape rooms usually alleviates the pressure of having to escape from the physical environment. Other mitigations are also conceivable, such as a lack of time pressure or less social presence of the participants. These restrictions presumably reduce the immersive experiences created by escape rooms. Nevertheless, the growing number of digital escape rooms suggests that valuable experiences are still achievable. Although digital escape rooms are unlikely to match the effectiveness of real-life escape rooms, there are several arguments in favour of using them. For example, the implementation costs are lower, there are no maintenance costs, it is simpler to adapt digital escape rooms than real escape room facilities and digital escape rooms are available to a much larger user base – users do not have to travel to the location just to play the escape room. Therefore, digital escape rooms can be seen as more accessible and have a raison d'être despite the loss of immersiveness. Admittedly, however, evaluations of digital educational escape rooms (DEER)

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in particular are very rare to date (Fotaris and df Mastoras, 2019), as also described in the following section 2, the literature review. For example, in their systematic review of digital educational escape rooms, Makri, Vlachopoulos and Martina (2021) found the use of pre- and posttests to evaluate learning effectiveness in only 4 out of 45 studies. Accordingly, this study is aimed at contributing to the state of knowledge based on the investigation of a DEER that is particularly characterized by its low-threshold creation and low-threshold use. This raises the question of whether such a DEER, despite its low-threshold creation and low-threshold use and the resulting lower level of immersion, is still capable of achieving effective learning and favourable learner prerequisites. In addition, the user experience needs to be evaluated as a mission-critical factor due to the multiple browser tabs that require handling.

The basis of the DEER is a 360° room of a waterworks, through which students are sequentially guided by a web-based form containing, among other information, multiple choice questions (MCQs) as the escape room-specific puzzles. 360° room is here to be understood as composite ("stitched") panoramic shots from different viewpoints within the real object, which allow the object to be virtually walked through. The remainder of the article is structured as follows. In the next section 2, the state of the literature is described. As described in section 3.1, the goals of this single case study include a general clarification of the potential of low-threshold DEERs to promote student learning. The methods in this mixed-methods study, which are outlined in section 3.2, include a questionnaire as well as semi-structured interviews. In Section 4, the results are presented. In section 5 the results are discussed, and limitations described. In section 6, we conclude based on the data collected that low-threshold digital escape rooms constitute a promising educational tool.

2. Literature Review

Participation in escape rooms as a leisure activity has become very popular in recent years, resulting in an almost hundredfold increase in the number of escape room facilities in the U.S. from the years 2014 to 2020 (Spira, 2020). Accordingly, escape rooms are also increasingly appearing in the scientific literature (Krekhov *et al.*, 2021). For example, Nicholson (2015) presents an analysis on the types, structure, puzzles, and participants of escape rooms. Wiemker, Elumir and Clare (2015) similarly categorize escape rooms, for example, into competitive escape rooms, which allow competition between multiple teams, and score-based escape rooms, where team success is measured using metrics such as points. Krekhov et al. (2021) describe a categorization of the puzzles used in escape rooms. They distinguish primarily between *Mental Challenges*, such as knowledge, and *Physical Challenges*, such as self-motion and agility. Further, Krekhov et al. (2021) extend escape rooms from the real world to digital escape rooms, i.e., escape rooms that take place in digital environments, such as digital computer games or virtual reality environments. Accordingly, they complement the *Emotional Challenges* category, which is afforded by simulation in digital environments. For example, without real-world consequences eliminable through digital environments, difficult and moral decisions or fear- and disgust-inducing situations can be turned into escape room challenges. Hence, digital escape rooms broaden the application purposes for escape rooms, which might also be beyond entertainment. Wiemker, Elumir and Clare (2015) have previously pointed out further possible uses, for example, enhancing teamwork skills, or improving skills such as critical problem solving or critical thinking. In line with this, Cohen et al. (2020) positioned escape rooms as a medium to study teamwork. Furthermore, Terlouw et al. (2021) examined an escape room game for triggering social interactions between children with autism spectrum disorder and their peers.

Among the consistently mentioned purposes of escape rooms is education. Various terms are used in the literature, such as educational escape rooms (Martina and Göksen, 2022), educational escape games (Klamma *et al.*, 2020), escape rooms for learning (Fotaris and Mastoras, 2019), or escape room-based serious games (Terlouw *et al.*, 2021). Sanchez and Plumettaz-Sieber (2019) define educational escape rooms by five traits: In addition to the (1) physicality of a space, these include the aforementioned (2) clues and puzzles as well as (3) teamwork, also (4) fantasy and play, and especially (5) unambiguous educational objectives. Accordingly, the attributes of educational escape rooms are manifold. In the following a selection of prevalent characteristics is described.

2.1 Educational Contexts

Educational escape rooms are used in a variety of educational contexts, for example, in school (Ambrožová and Kaliba, 2021; Bezençon *et al.*, 2023) or in vocational education (Karageorgiou, Mavrommati and Fotaris, 2019). According to Fotaris and Mastoras (2019), over 70% of scientific studies take place in higher education – Makri et al. (2021) attribute this to higher education's predominant research context featuring extended resources.

2.2 Subject Areas

The subject areas in which educational escape rooms are used are also diverse, such as STEAM (Science, Technology, Engineering, Art and Mathematics) (Karageorgiou, Mavrommati and Fotaris, 2019; Sidekerskienė and Damaševičius, 2023), public health (Bezençon *et al.*, 2023), or entrepreneurship education (Martina and Göksen, 2022). Almost 30% of the studies identified by Fotaris and Mastoras (2019) involve health and welfare, followed by natural sciences, mathematics, and statistics (22%), social sciences, journalism and information (19%), and information and communication technologies (15%). Conversely, (Makri, Vlachopoulos and Martina, (2021) identify science, technology, engineering, and mathematics (STEM) as the most common subject areas.

2.3 (Digital) Media

Likewise, educational escape rooms are created using different media – hybrid and digital educational escape rooms are created using digital media, for example, web-based (Ambrožová and Kaliba, 2021), or mixed reality technologies-based (Klamma *et al.*, 2020), such as marker-based augmented reality (Buchner, 2023). Regarding digital escape rooms, it is worth noting that in the systematic literature review by Fotaris and Mastoras (2019), 77% of the studies were based on physical settings, whereas only 13% were in hybrid settings and only 10% were in digital settings.

2.4 Design Frameworks

Different design frameworks for educational escape rooms exist. For example, Eukel and Morrell (2021) recommend a 5-phase cyclical design process consisting of the design, pilot, evaluate, redesign, and re-evaluate phases. This design process is intended to promote deep, lasting learning experiences. Fotaris and Mastoras (2022) propose *Room2Educ8*, a student-centered framework following design-thinking principles. *Room2Educ8* has been developed for supporting various types of escape rooms as well as for a wide range of subject areas.

2.5 Authoring Systems

DEERs do not have to be coded from scratch; in fact, several authoring systems have already been developed. Commercial authoring systems include *Telescape Live* (Buzzshot, 2023), *Breakout EDU* (Breakout Inc., 2023), and *Room Escape Maker* (ROOM ESCAPE MAKER, 2023). Furthermore, open-source platforms exist for implementing DEERs, such as *Escapp* (GING, 2023), which also provide functionality for formal educational contexts, such as student registration, team formation, progress monitoring, hint management and monitoring (López-Pernas *et al.*, 2021). Additionally, multi-purpose platforms, such as *Google Slides* (Grāvelsiņa and Daniela, 2021) and *Google Forms* (Vergne, Smith and Bowen, 2020), that can be used for DEER creation, are worth mentioning.

2.6 Complexity of Implementation

Low technical and organizational complexity of implementation of DEERs promotes their use. For example, Vergne, Smith and Bowen (2020) use a web-based form containing MCQs. A similar approach exhibiting promising results was used by the authors Wehking et al. (2022). Such low-threshold approaches are linked to a reduction of the game character, soften the requirement for fantasy and play (Sanchez and Plumettaz-Sieber, 2019), and usually consist of a sequence of simple tasks (Ambrožová and Kaliba, 2021).

While in recent years the focus has been on the technical and organizational implementation of DEERs, and DEERs overall seem to fall into an early stage of development (Fotaris and Mastoras, 2022), design principles from the perspective of learning theories, instructional design, or learning psychology are rather underrepresented in the literature. Only a few studies mention learning theories as a foundation, such as generative learning (Karageorgiou, Mavrommati and Fotaris, 2019). From an instructional design perspective, Buchner, Rüter and Kerres, (2022) claim that playing an escape room following a conventional learning activity yields greater retention and domain-specific self-efficacy with lower cognitive load than the reverse order. Likewise, Pozo-Sánchez, Lampropoulos and López-Belmonte (2022) have investigated differences of face-to-face and online escape rooms: face-to-face escape rooms provide more entertainment to students and activate them better, while in online escape rooms students' autonomy, creativity and exploration were increased. Pozo-Sánchez, Lampropoulos and López-Belmonte (2022) conclude that choosing escape room variants depends on the goals to be achieved. Learning analytics, i.e., the analysis of data characterizing learning processes, is also helpful for optimization of DEERs. Accordingly, López-Pernas et al. (2022) identify various profiles of students using learning analytics that merit consideration in DEER design.

2.7 Systematic Literature Reviews

A general overview of the current state of educational escape rooms is provided in three systematic literature reviews by Fotaris and Mastoras (2019), Veldkamp et al. (2020), and (Makri, Vlachopoulos and Martina, (2021).

Among the major benefits of educational escape rooms are training of meta skills such as teamwork, collaboration, critical thinking, problem solving, leadership and creativity (Fotaris and Mastoras, 2019). Engagement and motivation were also mentioned in most studies. Learning outcomes were seen as a benefit, as was social interaction, in just under a third of the studies. The biggest challenges are the so far poor state of evaluation as well as the time commitment on the part of the lecturers for facilitating educational escape rooms. Nevertheless, it should be mentioned that most of the studies have investigated physical escape rooms and escape rooms that were conducted in the classroom. Veldkamp et al. (2020) exclude digital escape rooms in their review. Nevertheless, their call for aligning escape room objectives with learning objectives seems to be highly salient. In contrast, Makri et al. (2021) specifically examined escape rooms using digital technology in their systematic literature review. They, too, deplore the low degree of evaluations. However, (Makri, Vlachopoulos and Martina, (2021) pointed to the need for debriefings for promoting learning outcomes. In this claim, they are supported by Sanchez and Plumettaz-Sieber (2019). In contrast to Fotaris and Mastoras (2019), (Makri, Vlachopoulos and Martina, (2021) see cognitive skills as the most common learning goals. In line with the lack of evaluations and in line with the low evidence-based application of educational escape rooms, the study described in the following section contributes to bridging the gap, especially for educational escape rooms that can be created and applied in a low-threshold manner.

3. Study

3.1 Background

The genesis and research questions of the study are presented in this section. Waterworks are facilities of technical infrastructure. The functional principles of waterworks are part of the learning objectives in planning and engineering courses. Accordingly, a 360°-based walk-through visualization of a waterworks was used as part of a virtual field trip (Wolf et al., 2021). To create this visualization, 360° footage captured by a consumer camera (Insta360 ONE X) were stitched together to form a 360° room using *Matterport* software (Matterport Inc, 2020) and supplemented with text and graphic annotations (Figure 1 and Figure 2). In the following learning scenario, students were instructed to explore the waterworks freely, following the approach of exploratory learning (Freitas and Neumann, 2009). The only instruction given was to follow the flow of the water. An evaluation of this learning activity revealed high student acceptance and reported decent learning outcomes. However, some students reported feeling overwhelmed by the opportunity for free exploration and requested more guidance. Such guidance – inspired by guided learning, e.g., described in (Billett, 2000) and in (Leutner, 1993)– may be provided in a DEER through sequential tasks to be solved. Low-threshold DEERs have already been reported to be implementable using web-based forms with little technical effort (Vergne, Smith and Bowen, 2020). Accordingly, a web-based form was developed that is sequentially worked through and has the functions of conveying information and providing tasks consisting of MCQs.

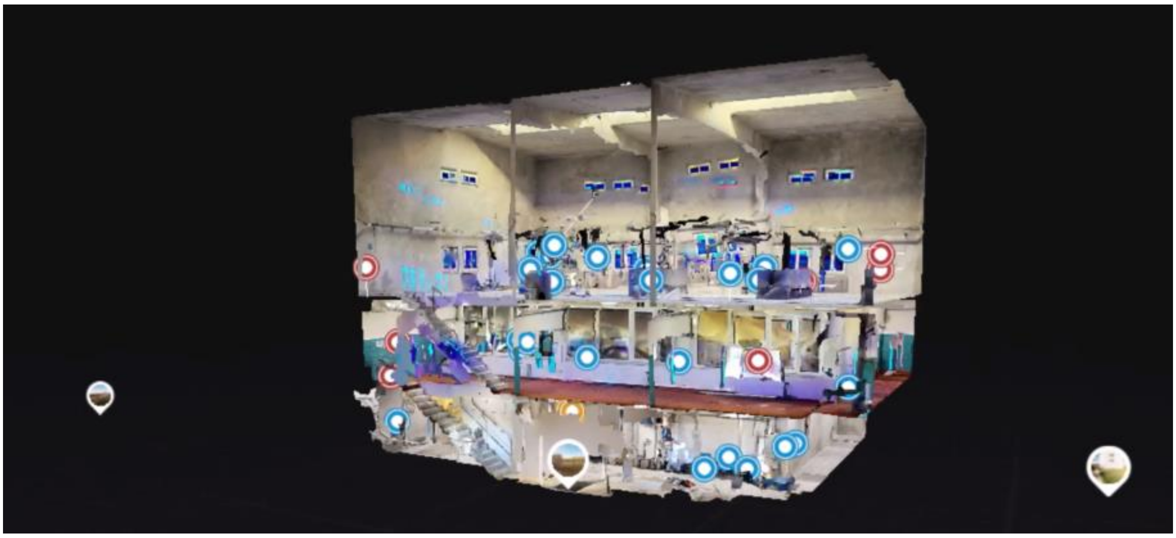

Figure 1: 360° room: Dollhouse View

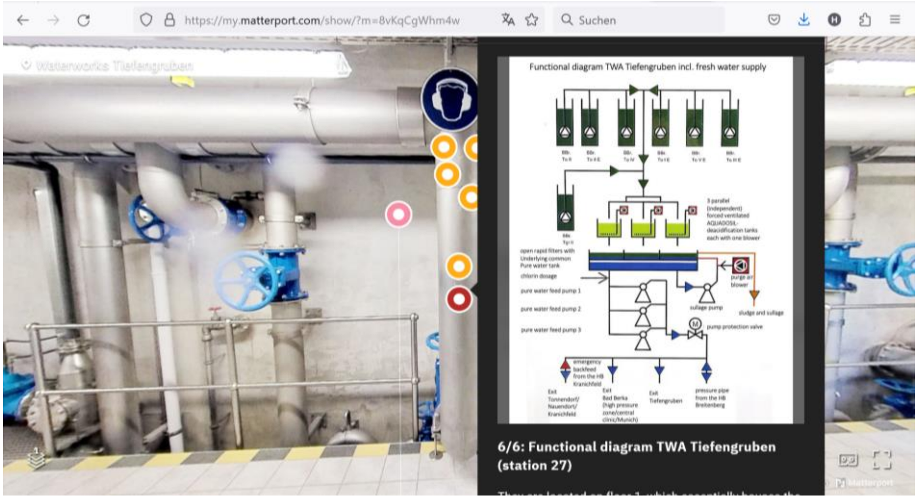

Figure 2: 360° room: Screenshot on the 1st floor showing an activated annotation

3.1.1 Web-based form

Google Forms was selected as the easy-access software providing web-based forms. To create the web-based form, the didactic concept that already existed for the annotations of the 360° visualization was extended. First, a schematic floor plan was developed for each of the three floors of the waterworks. The technical devices present on each floor, insofar as they also serve as points of interest (POI), were added to the floor plans. In addition, a sequence was developed in which the POIs were to be visited. A short instruction for students was then developed for each POI. The instruction describes the information to be acquired, e.g., using the form of text or graphic annotations, questions to be answered and gives a hint to the next POI to be visited. The questions correspond to the puzzles to be solved in an escape room. The question types used were single word questions and MCQs (Figure 3). The boss task, a task of higher complexity at the end, which is typical for an escape room, consists of a cloze text, which was also implemented using multiple MCQs.

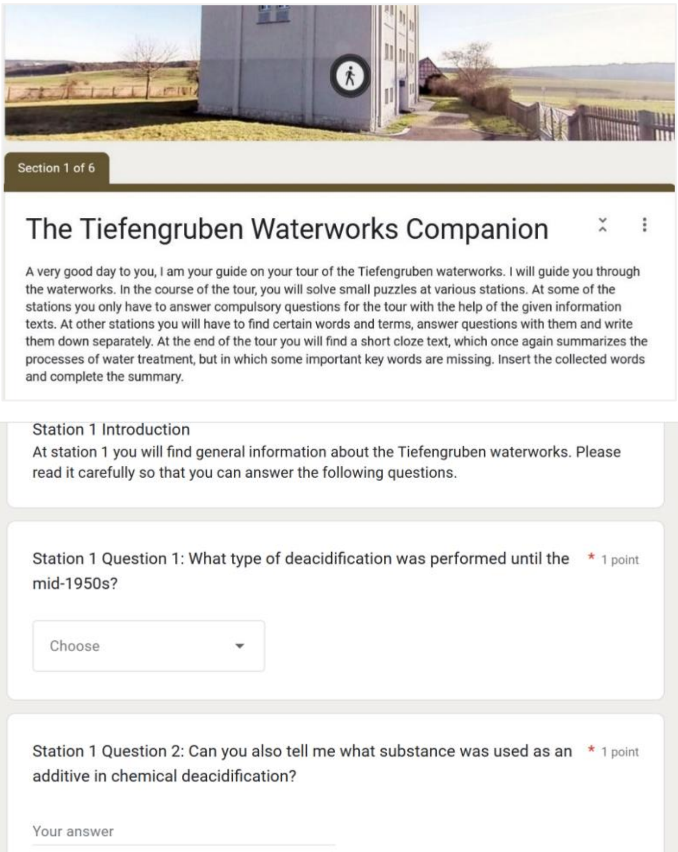

Figure 3: Introduction and sample questions of the web-based form

3.1.2 Learning scenario

The learning scenario included the 360° room and the Google Form. For both elements, the web link was given to the students with the instruction that they should individually explore the virtual waterworks, following the instructions and information provided in the Google Form. A potential time commitment of one hour was indicated. The exploration of the virtual waterworks was announced as a voluntary learning activity that supports the learning objectives of the respective course through the more practical knowledge of a field trip that can be attained via the DEER. Students had the chance to complete the DEER individually as part of a homework assignment over a 3-week period in the second half of each course. By answering 5 MCQs in the post-test, students were able to earn a maximum of 5 bonus points, which were applied to the written exam. These bonus points resulted in a high extrinsic motivation of students: When asked what impact the bonus points had in their decision to play through the escape room, a mean of M=4.1 (SD=0.9) was obtained on a 5-point Likert scale (1: no impact, I was solely interested in the waterworks and 5: I would not have been interested in the waterworks if I did not have the chance to gain bonus points).

The DEER described above, consisting of the 360° room visualization of the waterworks and the accompanying web-based form, was used in the learning scenario described and subjected to an evaluation study (Reinking and Alvermann, 2005). Alongside the general objectives of an evaluation study, such as analysing the effects of the intervention (Chang and Little, 2018), the following three research questions were examined in particular:

1. To what extent is the learning scenario accepted by students? (RQ1)
2. Are appropriate emotional and motivational learning prerequisites achieved? (RQ2)
3. Is an appropriate usability of the common handling of 360° visualization and web-based form achieved? (RQ3)

Answering these research questions is addressed by a mixed method study design using both qualitative and quantitative methods described below.

3.2 Methodology

3.2.1 Study design

The voluntary learning activity was presented to the students in a five-minute presentation by one of the researchers during a lecture. In addition to the educational added value to the course, the opportunity of earning bonus points and as well as the study embedding was presented. All information necessary was provided via the respective course room in the learning management system (LMS, Moodle). Contrary to the usual design of an escape room-based learning scenario, students were asked to complete the DEER individually, without a time limit and using non-immersive desktop VR on a notebook: one browser-window contained the web-based form and the 360° room was displayed in another window. The goal of that choice was to evaluate the guidance feature of the web-based form in a more isolated way, excluding group effects during the learning scenario. The first step of the study was a pretest consisting of 5 randomly selected MCQs from a pool of 15 MCQs about the waterworks. Then, students had the opportunity to accomplish the DEER. Finally, students participated in a post-test, which again consisted of 5 MCQs from the pool already used in the first step. Thereafter, the students were asked to answer a questionnaire. The questionnaire included demographic data, such as gender and age group. Furthermore, students were asked about their perceived prior knowledge and their perceived knowledge about the waterworks. The main parts of the questionnaire were three standardized research instruments. We looked at learning prerequisites, as these are particularly pertinent to the learning effectiveness of the DEER. As proxies for learning prerequisites, we specifically analysed emotion and motivation. The learner requirement motivation was assessed by the Questionnaire to Assess Current Motivation in Learning Situations (QCM) (Rheinberg, Vollmeyer and Burns, 2001). Further, emotions were measured by the Achievement Emotions Questionnaire (AEQ) (Pekrun *et al.*, 2011). Finally, the Questionnaire User Experience (QUX) (Müller, Heidig and Niegemann, 2012) was used to assess usability traits of the DEER. The QUX has been designed as a comprehensive assessment instrument for websites and records various categories of websites correspondingly. These categories include functional and non-functional qualities as well as emotions and an overall assessment. The variety of categories covered also implies the use of different scales by the QUS. Thus, the QUX uses 6-point Likert scales for rating functional qualities and a 10-point polarity profile for describing non-functional qualities of web-resources. Both, the 360° room and the web-based form are to be considered as web-resources rendering the QUX an appropriate measurement instrument. Lastly, 15 randomly selected participants were invited to a semi structured interview. The semi-structured interview was divided into the themes "General assessment", "Learning" and "Implementation". There were a total of 19 key questions, which were asked in the interview depending on the flow of themes. Care was taken to ensure that all three themes were covered in each interview. The time frame for the interviews was 15 minutes, which was attained in all cases. In the end, 13 interviews conducted via videoconference were obtained. The interviews were transcribed by the two authors, who acted as interviewers, during the interview and were then subjected to qualitative analysis (Schmidt, 2004). Likewise, such qualitative analysis was applied to the answers to an open-ended question in the questionnaire, asking for participant's observations. In both cases, the qualitative analysis was conducted by two of the authors as reviewers using a spreadsheet software for documentation. Divergent findings were discussed to reach a common assessment. Informed consent was available for all participants.

Demographics. The learning scenario conducted in three different cohorts with N=76 participants (Table 1). 42 participants identified as male, 34 as female. In terms of age, the age groups were populated as follows: 18/19: 2, 20/21: 25, 22/23: 31, 24/25: 11, and 26/27: 4. Three participants reported being older than 27 years. Data from three participants was excluded due to incomplete datasets. The learning scenario was offered in two different courses, each of which included students from two undergraduate programs: one was 45 students in Urban Studies and the other was 30 students in Civil Engineering. In both courses, the learning scenario addresses the learning objective of providing an overview of the components and functioning of a waterworks.

Table: 1 Cohorts

Cohort #	Semester	Course	N
1	Winter Term 2021	Urban Water Management	16
3	Winter Term 2021	Urban Water Technology	28
5	Winter Term 2022	Urban Water Technology	32
		Sum	76

4. Results

4.1 Quantitative Findings

4.1.1 Learning outcomes

Participants reported a mean of 63.2 minutes when asked about the duration of the learning scenario (range: 20 - 120 minutes, SD: 23:28 minutes). There was no technical limit to the response time for the pre-test and post-test. The pretest averaged 8.11 out of a possible 10 points. On average, the students needed 16:35 minutes (range: 0:47 - 115:00 minutes, SD: 25:28 minutes). In the post-test, students improved to a mean of 9.47 (out of 10 points). The post-test took the students a mean of 7:18 minutes (range: 0:32 - 76:00 minutes, SD: 12:25 minutes). Students were able to score higher on the post-test in less than half the time. This learning outcome is more evident in the students' self-assessment. They selected on a 10-point scale their perceived knowledge before and after the learning scenario: while before the learning scenario knowledge was rated M=3.1 out of 10 points, after the learning scenario it was rated 6.8 out of 10 points. The levelling effect for the learning outcomes is also clear: the respective standard deviation decreases from SD=2.32 to SD=1.65. Several students needed more than one hour to complete the pre-test. This indicates that the pre-test might have been conducted in parallel with the exploration of the waterworks, contrary to the instructions. This practice might have led to an increase in points scored in the pre-test. The high scores obtained in the pre-test and post-test suggest that the questions might have been too simple and not very selective.

4.1.2 User experience

The QUX (Müller, Heidig and Niegemann, 2012) first assesses the functional qualities of the DEER (Figure 3). In general, the DEER is rated as sufficiently easy to understand (b) without the need for prior instruction (d) to learn the operation quickly (a), to develop confidence in the operation of the software (c), and to be able to work through the software well (e). Dropping in the students' evaluation are the statements that the information is easy to find (h) and the goal of using the software is easy to achieve (f) and the layout is clear (g). In our view, this constellation is to be interpreted as an indication that the handling of the software is simple and comprehensible, but also complicated in some parts. The rather low values point to the complexity of the task: the value of 3.2 for item (h) "The information I am looking for is easy to retrieve" is below the mathematical average of 3.5. The reason for this low value may be that there are no direct links into the 360° model for questions posed by the web-based form. Thus, learners must search, which sometimes requires time and effort.

Another reason for rather low scores may be the inconvenient handling of several web browser windows mentioned also in the qualitative results.

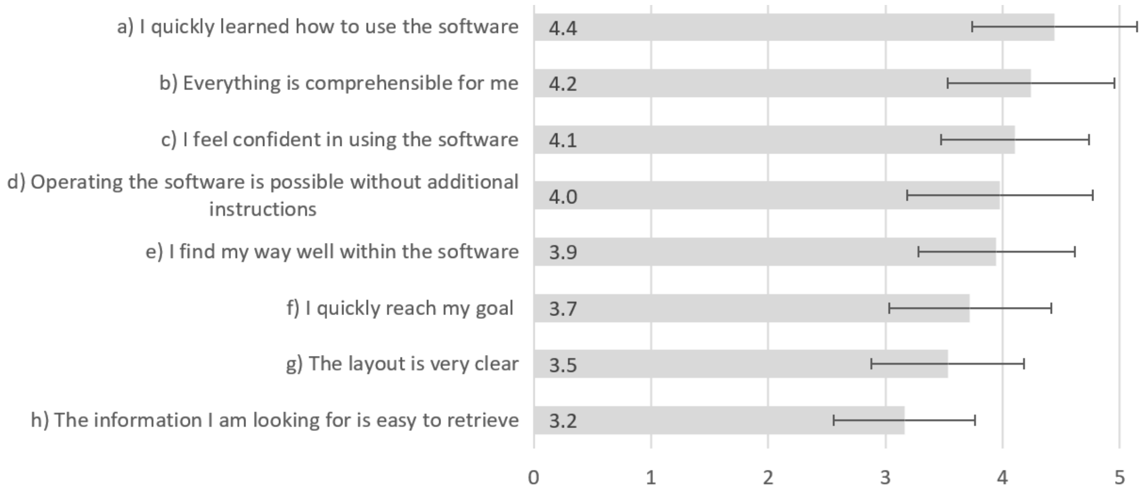

Figure 3: QUX: Functional Qualities (6-point Likert scale)

This assessment of inconvenient handling seems to be confirmed by the evaluation of the non-functional qualities (Figure 4). The poles such as convenient (k), activating (j), appealing (i) and aesthetic (h) are found at the lower end of the evaluation. The usefulness of the DEER per se is evidenced by high ratings for positive image (a), interesting (b), and creative (c). The attributes valuable (d), professional (e), thrilling (f), and attractive (g) are found in the rating midfield. The absolute differences of the ratings in the 10-point polarity profile are rather small, but these differences might also hint at the fact that the DEER is perceived rather positively in its core of virtual field trip and escape room, but that the handling is seen as less convenient.

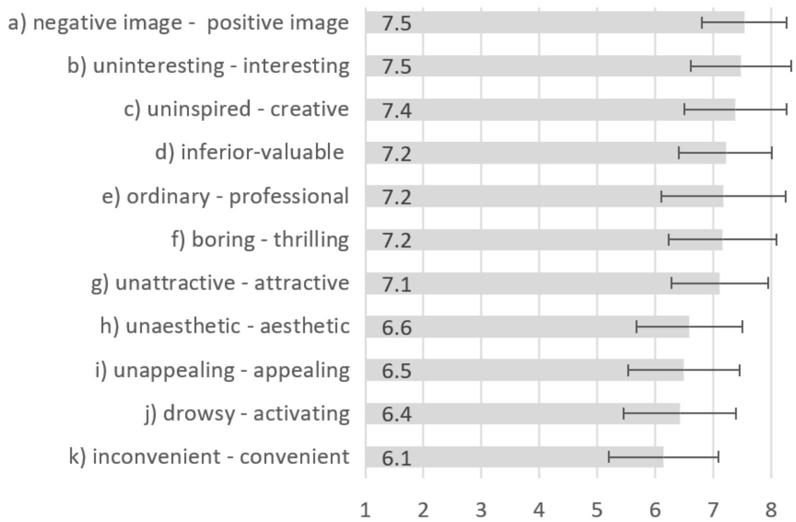

Figure 4: QUX: Non-Functional Qualities (10-point polarity profile scale)

Further, with the QUX the overall impression by using four items is measured (Figure 5). Again, the usefulness of the DEER is recognized, with the intention to reuse is being rated highest (a) as well as the prospect of recommending it to others (b). Likewise, liking (c) and aesthetics (d) of the DEER are rated lower. As mentioned before, this might be interpreted as an indication of the previously already apparent non-optimal combination of 360° visualization and web-based form.

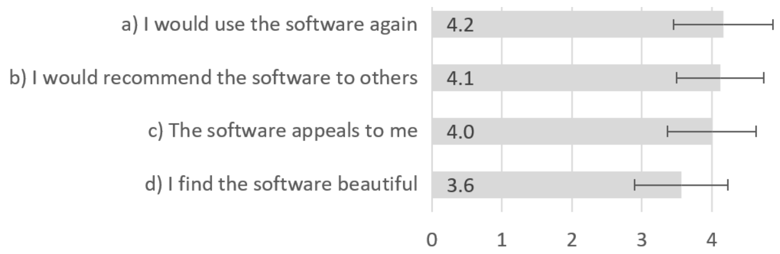

Figure 5: QUX: General statements (6-point Likert scale)

4.1.3 Emotions

Emotions are recognized as an important prerequisite for successful learning (Tyng *et al.*, 2017). Accordingly, emotions were assessed using the AEQ (Pekrun *et al.*, 2011). Here, the 8 specified sample items for learning related emotions were used (Pekrun *et al.*, 2011, p. 47) (Table 2). Notably, the emotions with positive connotations (Hope, Enjoyment, and Pride) received the highest scores. With Hope as the emotion rated at the highest, Hopelessness is correspondingly rated at the lowest. Shame and Boredom also receive low scores. The emotions with the highest negative connotations are Anger and Anxiety. This rating might be explained by the qualitative evaluation, in which reference is made to some puzzles that are difficult to solve. Overall, the emotions as measured by the AEQ are to be classified as conducive to learning, but the values for Anger and Anxiety, which are deemed to be elevated, should be kept in mind when revising the learning scenario. This assessment is also based on the emotion scores collected through the QUX (Table 2): Students report above average scores (3.5 on a 6-point Likert scale) for “I feel motivated” but only below average scores for “I feel fortunate” and “I feel happy.”

Table 2: Emotions

Questionnaire	Emotion	M	SD
QUX (6-point Likert)	I feel motivated	3.9	1.16
	I feel fortunate	3.0	1.23
	I feel happy	3.0	1.14
AEQ (7-point Likert)	Hope	5.1	1.4
	Enjoyment	4.8	1.56
	Pride	4.1	1.69
	Anger	3.4	1.78
	Anxiety	2.8	1.7
	Boredom	2.4	1.61
	Shame	2.1	1.47
	Hopelessness	2.1	1.46

4.1.4 Motivation

Motivation is also regarded as one of the fundamental prerequisites for learning processes (Pintrich, 2003). Accordingly, the QCM (Rheinberg, Vollmeyer and Burns, 2001) was used to assess motivation (Figure 6). The results show a typical structure in the four subscales: Probability of Success (3.7), Interest (3.2) and Challenge (3.1) are above the mathematical mean of 3.0, while Anxiety (2.5) is below the mean. The high value for Probability of Success and the somewhat lower value for Challenge seem to indicate a manageable task. The value for Interest, which is barely above the mean, may reflect the high extrinsic motivation already observed due to the additional points. The low value of Anxiety, which is in fact high in comparison to other learning activities, (Rheinberg, Vollmeyer and Burns, 2001; Söbke, Arnold and Montag, 2020) could be affected through partial difficulty to solve tasks. Overall, the motivational situation does not seem to be detrimental to learning success but should likewise be kept in mind when revising the DEER.

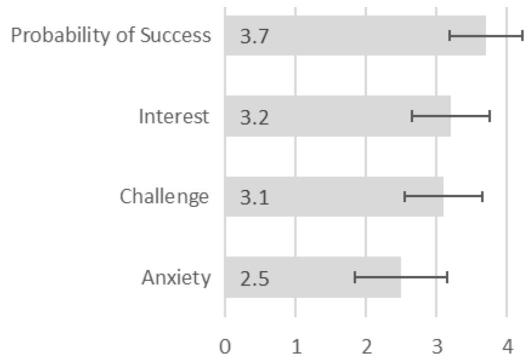

Figure 6: QCM: Subscales (5-point Likert scale)

4.2 Statistical Analysis

Apart from descriptive statistics, the study design did not include statistical analysis of the quantitative data as a primary goal. Nevertheless, it seems worthwhile analysing the data for incidental findings. Thus, within the statistical analysis, it is investigated whether differences exist regarding the acceptance of the DEER with respect to gender and the faculty to which the participants belong. T-tests were performed on the independent variables *Gender* (male vs. female) and *Course of Study* (Urban Studies vs. Civil Engineering) for all items of the QCM, AEQ and QUX. The effects found are presented in Table 3 and Table 4. Reported below are significant results at an alpha error level of 0.05 as well as results with an alpha error level between 0.05 and 0.1, which may be regarded as a tendency.

Gender. Although only small effects were found with respect to gender differences (table 3), some patterns are apparent. Female participants report a greater challenge on a motivational level, but also a higher interest than male participants. Females also rate the software more often as, e. g., valuable and activating. Also, more positive emotions are reported for *Enjoyment*, *Hope*, *Pride*, and *Boredom*.

Table 3: t-tests: Effects found for Gender (< 0.05 ("significant"), *<0.1 ("tendency)*)

Independent variable: **Gender**	**female (n=41)** M (SD)	**male (n=34)** M (SD)	
Interest (QCM)	3.342 (0.758)	2.953 (0.904)	t(73)=2.025, **p=.047**, d=0.231
Challenge (QCM)	3.213 (0.690)	2.735 (0.870)	t(73)=2.653, **p=.010**, d=0.297
Impressions: inferior-valuable (QUX)	7.610 (1.595)	6.740 (1.524)	t(73)=2.412, **p=.018**, d=0.272
Impressions: activating - drowsy (QUX)	3.900 (1.530)	5.380 (2.104)	t(73)=-3.521**, p=.001**, d=0.381
Impressions: creative - uninspired (QUX)	3.290 (1.834)	4.000 (1.651)	t(73)=-1.739, *p=.086*, d=0.199
Impressions: uninteresting - interesting (QUX)	7.880 (1.400)	7.000 (1.985)	t(73)=2.240, **p=.028**, d=0.254
Impressions: unappealing - appealing (QUX)	6.850 (2.019)	6.060 (1.757)	t(73)=1.799, *p=.076*, d=0.206
Functionality: The layout is very clear (QUX)	3.290 (1.436)	3.820 (1.086)	t(73)=-1.774, *p=.080*, d=0.203
Enjoyment: I enjoy acquiring new knowledge (AEQ)	5.200 (1.308)	4.350 (1.756)	t(73)=2.314**, p=.024**, d=0.286
Hope: I have an optimistic view toward studying (AEQ)	5.370 (1.299)	4.710 (1.467)	t(73)=2.065, **p=.042**, d=0.235
Pride: I'm proud of my capacity (AEQ)	4.460 (1.675)	3.710 (1.661)	t(73)=1.957, *p=.054*, d=0.223
Boredom: The material bores me to death (AEQ)	1.900 (1.241)	3.090 (1.798)	t(56.891)=-3.255, **p=.002**, d=0.396

Faculty. Regarding the course of study to which the participants belong, some small effects and tendencies can also be identified. Civil Engineering students report that they are happier with the software, and they also find it more thrilling and appealing than architecture and urban studies students. It could be argued that Urban Studies students are more demanding in terms of the aesthetical design of the environment, while Civil Engineering students focus more on the function and facts. The differences could also reflect that the waterworks contains some technical details that are more relevant to Civil Engineering students. This could, for example, explain the higher Interest (QCM) of Civil Engineering students. For the items of the AEQ, on the other hand, no differences were found between the two courses of study.

Table 4: t-tests: Effects found for Faculty (CE = Civil Engineering, US= Urban Studies, < 0.05 ("significant"), *<0.1 ("tendency)*)

Independent variable: **Course of Study**	**CE (n=30)** M (SD)	**US (n=44)** M (SD)	
Interest (QCM)	3.353 (0.838)	3.023 (0.836)	t(72)=1.669, *p=.099*, d=0.193
Emotion: Happy (QUX)	3.270 (1.081)	2.730 (1.149)	t(72)=2.031, **p=.046**, d=0.233
Impressions: thrilling - boring (QUX)	3.170 (1.704)	4.250 (1.882)	t(72)=-2.525, **p=.014**, d=0.285
Impressions: creates a positive image - creates a negative image (QUX)	3.000 (1.339)	3.770 (1.492)	t(72)=-2.278, **p=.026**, d=0.259
Impressions: unappealing - appealing (QUX)	7.000 (2.117)	6.160 (1.765)	t(72)=1.855, *p=.068*, d=0.214
Impressions: aesthetic - unaesthetic (QUX)	3.500 (1.570)	5.050 (1.791)	t(72)=-3.827, **p=.000**, d=0.411
Functionality: The layout is very clear (QUX)	3.930 (1.112)	3.250 (1.383)	t(72)=2.253, **p=.027**, d=0.257
General: The software appeals to me (QUX)	4.370 (1.098)	3.750 (1.349)	t(72)=2.077**, p=.041**, d=0.238
General: I would use the software again (QUX)	4.600 (1.276)	3.840 (1.462)	t(72)=2.307, **p=.024**, d=0.262
General: I find the software beautiful (QUX)	4.170 (1.206)	3.110 (1.280)	t(72)=3.556, **p=.001**, d=0.387
General: I would recommend the software to others (QUX)	4.570 (1.104)	3.800 (1.268)	t(72)=2.703, **p=.009**, d=0.304

Although individual effects were detected by statistical analysis, they do not yet provide a clear overall picture. In further work, such effects need to be identified, e.g., by using learning analytics, so that they might be constructively incorporated into the design of DEERs.

4.3 Qualitative Findings

Participants were able to express their own thoughts about the learning scenario within an open-ended question asked in the questionnaire. In addition, semi-structured interviews were conducted after the completion of the learning scenario. Prominently mentioned topics of the questionnaire were also included in the semi-structured interview.

4.3.1 Questionnaire

In the questionnaire, the participants were asked in a concluding open question about further impressions of the learning scenario. A total of 39 participants responded here, to which 77 codes were assigned. Multiple responses are indicated below. In cluster **(1) General Impression**, the learning activity was assessed as positive a total of 14 times; there was one negative assessment. In cluster **(2) Characterization**, general statements about the learning scenario were gathered. The statements included that the learning scenario achieved a level of authenticity that is only surpassed by real-life environments (4 times). The learning activity was also characterized as fun (3 times). An alternative way of teaching was mentioned twice. The possibility of the self-directed learning at one's own pace was praised. Contradictory were the statements that a learning experience was missing and on the other hand that the 360° room had created such a high immersion level that the web-based form had been forgotten. Regarding the **(3) Didactic Scenario**, the bonus points for the exam were mentioned positively (2 times). It was desired to make the presentation of the learning activity in the LMS clearer (2 times) and there was a complaint about not communicating the limited processing period sufficiently. Among the **(4) Design Details**, the site map and the web-based form were praised 2 times each. The built-in video annotations were equally mentioned as positive. In the cluster **(5) Usability** problems were mainly collected. For example, the operation of the floor selector of the 360° room is not intuitive (3 times). Two times each, the usage on a tablet or cell phone was mentioned as challenging as well as the unrecognized scroll option of text annotations. Other mentions include the challenging handling of the browser windows, the difficulty in getting to the exterior views of the 360° rooms, the generally non-intuitive operation, the overview of floor plans that could be improved, and very small text fields. Among the **(6) Problems** encountered the incorrect word puzzle dominated (16 times). In addition, 2 comments pointed out that the 360° room could not be displayed at all for certain tablets or smartphones. Several **(7) Improvements** were also suggested. Three times the linking of the stations to be visited in a certain order was suggested. Two times the variant of visually highlighting the next station was mentioned. More video annotations showing explanations by staff members were also mentioned (2 times). Other requests for improvement include a progress bar, audio loops and the integration of floor plans.

4.3.2 Semi-structured interviews

Interviews were conducted with 13 participants, which are abbreviated in the following as I1 to I13. The semi-structured interviews were conducted by two researchers. The guiding questions were divided into three themes. The theme **General Impression** asked about the overarching impression regarding the learning scenario and whether re-participation in a similar learning scenario would be likely. The theme **Learning** was hardly represented in the answers to the open question of the questionnaire. Accordingly, it was asked to what extent the interviewees considered the learning scenario to be conducive to learning and how the learning scenario contributed to a stronger understanding of water processing. Likewise, interviewees were asked about the appropriateness of the learning content and about a comparison with conventional methods. In the Theme **Delivery**, details of the delivery of the learning activity were addressed, such as how often the tour was walked, what technical challenges were encountered, and to what extent the guidance and navigation was clear.

In the qualitative analysis of the interview data, a total of 272 statements were categorized and clustered. All statements with at least 3 mentions are presented below. In the theme **General Impression**, all 13 interviewees reported a positive overall impression and a very successful learning activity, and all would participate in a similar learning activity again. The sound structure was lauded (3 times), which led to a sound impression of the waterworks as the process (4 times). Three interviewees named it helpful seeing the theoretical knowledge in practice. The letter search was mentioned negatively 7 times, while 6 times the quality of the 360° room and the guidance through the web-based form were complimented.

In the theme **Learning**, the cluster *Appropriateness* is found. 6 interviewees perceived the content to be appropriate, while 4 urban studies participants categorized the content as too comprehensive. Likewise, the order of the stations was found to be reasonable, and the annotations were marked as comprehensible. In the *Replacement for Field Trips* cluster, only partial replacement was confirmed by 7 interviewees. The success of the learning scenario was reported by a total of 6 respondents, ranging from 60 to 120% of a real field trip. Also, six times the learning activity was suggested as a supplement to a real field trip, for example as a follow-up. The lack of opportunity for follow-up questions was mentioned seven times as a significant learning-relevant difference to a field trip. In the *Knowledge Acquisition* cluster, 6 interviewees stated that they had learned new knowledge, in contrast to 5 interviewees who rather emphasized the consolidation of basic knowledge learned in lectures. The appropriateness of the learning scenario for students who prefer visual information was emphasized by 5 interviewees. Remarkable is the statement of 4 interviewees that interpersonal contacts were missed. On the other hand, the opportunity for self-directed learning was mentioned positively 6 times.

In the theme of **Delivery**, initial difficulties in operation were expressed three times. When asked about the number of iterations through the 360° room, 9 of the interviewees stated having carried out the process exactly once. In contrast, 3 interviewees stated that they had iterated back and forth several times. Likewise, 3 interviewees expressed that they had jumped back specifically to look up details when needed. In the *Suggestions for Improvement* cluster, the videos already mentioned in the written survey including those of technical processes (9 times) were mentioned. Four interviewees would like to see a tutorial that cannot be skipped, while 3 times it was requested that the POIs in the 360° room have the same numbering as in the web-based form. Three times the permanent provision of the learning scenario was requested to enable learning outside of bonus points.

The interviews addressed the learning scenario as a whole and did not ask about specific components, as the functionality of the learning scenario was to be explored. Nevertheless, the web-based form is the implementation of the escape room metaphor. Accordingly, the few statements about the web-based form will be reproduced here. Two interviewees stated that they first started to explore the 360° room on their own and then used the web-based form to walk the 360° room systematically. Once – as in the questionnaire – it was pointed out that the web-based form opened in a different browser tab was forgotten during the exploration of the 360° room. Two other interviewees complained that the web-based form was not intuitive. The text-heavy nature of the web-based form was also mentioned, and more graphics were requested.

4.3.3 Selected statements

For providing a more profound impression of the qualitative results some quotes from the interviews that may be considered representative to characterize the learning scenario are presented. The advantages of the learning activity were clearly elaborated by some interviewees. Accordingly, I13 praises the self-directed learning scenario:

> *"In addition, you then engage more intensively with things yourself and are then also more attentive or have a longer attention span than as in a long monologue."*

I9 summarizes the learning outcomes, the connection with visual orientation, and the appropriateness of information granularity as follows:

> *"I definitely understood the structure [of the waterworks] and how water is treated much better. The direct visual images help me to learn, and I can now directly understand different terms because I have a picture in mind. Some of the information was very detailed, but I felt it was not too much."*

Both in the adequacy of the information and in the visualization, I13 concurs:

> *"The information was summarized briefly, so it was pleasant to be able to comprehend it, I wouldn't say too detailed - especially the drawings and videos made the processes more comprehensible."*

Regarding the learning successes, I9 comments that it is not so much the concrete factual knowledge that was remembered, but.

> *"It's more the pictures - that if I heard the name now, I could directly relate to."*

In this context, answers to the questions asked in some interviews about specifically remembered details also seem to be interesting. For example, the darkened windows on the third floor were mentioned a total of 4 times, and the filter basins were mentioned twice - each visually impressive details of the waterworks. Referring to the web-based form, I11 expressed that this was…

> *"… not essential to the exercise if students feel like exploring."*

This utterance coincides with the reason for using the web-based form as a motivating and guiding element and shows that the learning activity may be done optionally with or without the web-based form – the escape room metaphor. I5 indicates the importance of good usability for learning success:

> *"[I failed] but miserably […] to get to the top floor and then after 7 min I found out that you can also change floors on a button at the bottom left and this also worked. Anyway, after that I was so annoyed that I didn't remember anything. The too-small info cards then added the rest to my emotional pomposity, so little stuck technically."*

The fact that the learning activity was honoured by the students despite all the introductory problems is summarized by I12 in a concluding wish:

> "*That they keep working [on such learning scenarios] and spread it among the student body that we have such projects at the university*."

5. Discussion

Overall, both the quantitative and qualitative results reveal a learning scenario that is accepted and considered valuable by the students. The quantitative results document the learning conduciveness of the learning scenario regarding the learning prerequisites emotion and motivation. The technical setting of 360° room and web-based form can be attributed to sufficient usability. The qualitative results especially show a high basal satisfaction with the learning scenario. In particular, the unique selling points in comparison with conventional learning activities are also highlighted, such as the visual presentation and the opportunity for exploration. However, on this sound starting point, several areas for optimization that need to be addressed in the next iterations of the DEER were identified. They are mentioned below:

5.1 Predominance of the 360° Room

Especially in the qualitative studies, the 360° room was the focus of comments. The web-based form was mentioned much less, it seemed to integrate inconspicuously into the learning activity. The inconspicuousness was probably favoured by the low-profile framing of the web-based form as a companion. To justify framing it as an escape room with challenging and fun-generating game mechanics and thus reduce the dominance of the 360° room, game mechanics, in this case especially the puzzles to be solved, must be valorised. Measures to balances this prevalence include the integration of the 360° room with a digital world, such as WorkAdventure (WorkAdventure, 2023). It is also conceivable to use a digital escape room framework, such as Telescape Live (Buzzshot, 2023). However, the extent to which the technical and organizational low threshold is maintained must be taken into consideration.

5.2 Detailing Didactic Information

Especially, urban studies students indicated that the level of detail of the learning activity information was too fine-grained. While the use of target group-specific didactic skins was previously suggested for the 360° space (Wolf et al., 2021), it makes sense to develop separate web-based forms for each of the different target groups, whether subject-specific or degree-specific (Master vs. Bachelor).

5.3 Low Scores for Learning Prerequisites

The scores for learning requirements (here: usability, emotion, and motivation) are consistently lower than those of previously studied learning activities (e.g., (Wolf et al., 2021a, 2021b). From our point of view, these reduced values do not question the design of the learning activity, but rather are explained multifactorial:

4. The learning scenario in this study was completed by each student individually. This is to be seen as a major deviation from the escape room metaphor. However, we took this deviation into account particularly to focus the study on the two technical foundations of the learning activity (360° room and web-based form). The intended implementation of the learning scenario in groups will likely, following the principles of situational learning (Lave and Wenger, 1991), lead to a reduction of emerging difficulties and have a positive effect on the learning prerequisites.
5. Handling the software with two different web browser tabs is rather inconvenient for single-screen devices, such as smartphones, tablets, and notebooks. This could probably be counteracted with the integration of 360° room and web-based form.
6. The flaws in various word puzzles, which were only fixed in the later cohorts, certainly contributed to irritation, and reduced the measured values. These effects should no longer occur now.

5.4 GDPR Compliance

In the learning scenario, Google Forms was used as a web-based form for prototyping purposes. Google Forms is viewed critically from a data protection perspective in Germany. Therefore, an alternative has yet to be found for regular operation in teaching.

5.5 Future Work

An essential result of the study is the limited usability resulting from two different web browser tabs. An integrated solution that combines the puzzle tasks and 360° room in one space is to be striven for. At the same time, the strength of the DEER's ease of implementation should not be sacrificed for such an integrated solution. Thus, we are currently preparing a DEER using the low-threshold collaboration environment WorkAdventure (WorkAdventure, 2023). On the one hand, this will enable the integration of guidance, tasks, and the spatial environment. On the other hand, it is feasible for each learner to be represented by an avatar in the environment, presumably strengthening social presence and enabling embodiment effects. Another aspect that is to be strengthened in future is the tasks to be solved. At present, they are largely based on multiple-choice questions with limited entertainment value. Consequently, the game character of the escape room is neglected. An approach to a solution is the use of gamification mechanisms that also utilise the spatial dimension of the DEER (Das *et al.*, 2022). For example, one task could be to ask learners to navigate to a specific location in the DEER and thus train spatial expertise.

Furthermore, we consider a taxonomy of escape rooms missing that might assist to delineate escape rooms between the poles of "entirely in a physical, enclosed space" and "entirely digital using an electronic device". Any such taxonomy, which also includes other design features such as the involvement of facilitators, game, and puzzle mechanics, multiple or single users, would be extremely beneficial in categorizing the numerous escape rooms that are available.

5.6 Limitations

Certainly, the study also shows some limitations, which will be described in the following.

7. **Pre- and Post-Test.** The questions of the pre- and post-test turned out to be insufficiently selective, so that a ceiling effect could be observed. Nevertheless, the learning effectiveness of the DEER was demonstrated. Similarly, pre-test and post-test lacked a time limit. It is likely that the pretest was taken by some students during the learning scenario and indicated increased scores for actual prior knowledge. Furthermore, it was possible that due to the pool of questions, some participants could receive the same questions in the post-test as in the pre-test. However, a potentially confounding effect is reduced by only posing 5 questions from the pool of 15 questions at any one test. In addition, the correct answers in the pre-test were not disclosed. In future studies, the pre-test and post-test should consist of two separate sets of questions.
8. **Adoption of Evaluation Instruments.** The evaluation instruments were used in a moderately modified manner, as described in the following. The QUX (Müller, Heidig and Niegemann, 2012) for determining usability was developed specifically for evaluating websites. This is fitting here, as both components of the learning activity (360° room and web-based form) are operated as websites. A limitation could arise from the nature of the learning scenario. The recommendation for the QCM is to employ it before the learning scenario. For simplification reasons (only one questionnaire), the QCM data was collected following the learning scenario. Nevertheless, to maintain validity, students were asked to refer to a similar learning scenario yet to be completed when answering. Furthermore, a 7-point Likert scale was used for the AEQ, which was originally designed based on a 5-point Likert scale. Likewise, the QCM, which was validated for a 7-point scale, was used with a 5-point scale. (Dawes, 2008), though, succeeded in showing that 5- and 7-point Likert scales produce highly similar scores. Irritation could be caused by the different scales of the QUX 6-point Likert scales and 10-point polarity profile, which, however, were used in this study in the validated form. Overall, there is a debate about when to employ Likert scales with (such as 6 point) or without midpoint (such as 5 or 7 point) (Chomeya, 2010; Chyung *et al.*, 2017). In general, however, we believe that the adapted use of the scales yielded valid results given the evaluative character of the study.
9. **Bias due to quasi-voluntariness.** The learning scenario was not mandatory. Only students who voluntarily participated in the learning activity were surveyed. Admittedly, voluntariness was constrained by the bonus points attainable for the exam. Presumably, voluntariness is to be seen as having a measurement-improving effect.

6. Conclusion

Web-based forms offer a simple, technical, and organizational low-threshold option for converting 360° rooms into digital educational escape rooms (DEERs). Intended effects are increased motivation and guidance through the 360° room. Guidance has been suggested by some students who feel overwhelmed by the free exploration of 360° rooms. To date, however, such approaches have not been described in the literature. Accordingly, in this study, an existing 360° room was extended into a DEER using a web-based form and made to be applied in undergraduate courses. The application was conducted using pre- and post-tests to evaluate learning outcomes, a questionnaire to determine learning prerequisites (emotion, motivation, and usability), and semi structured interviews to qualitatively assess additional aspects. The results substantiate learning outcomes, suitable learning prerequisites (RQ2), a decent usability of the DEER (RQ3) and acceptance by students as an alternative learning scenario (RQ1). Among the noteworthy advantages is self-directed learning at one's own pace, while the lack of opportunity to interact with guides was claimed to be disadvantageous. The study also identified several potential improvements, which are now being successively implemented. At least for a good part of the students, a web-based form is an aid for guiding them through the 360° room. Together with the variant including no web-based form, students can be offered a choice depending on their own preferences. However, there is still work necessary to deepen the playful escape room character, while maintaining the technical and organizational low-threshold accessibility. Overall, the study demonstrated that complementing a 360° room with a web-based form can provide a low-threshold accessible DEER as foundation of a productive learning scenario. Thus, the present study contributes to the further variation of learning scenarios based on 360° rooms and expands the corpus of empirical evidence of DEER applications.

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Escape Rooms as Tools for Learning Through Failure

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Abstract: The increasingly neoliberal course of Higher Education is linked to rises in student anxiety around assessment and increased fear of the consequences of failure. Making mistakes is an inevitable part of any learning process (and of life generally) and managing failure in a productive and positive way is crucial for success and wellbeing beyond university. In this article, we argue that academia does not adequately prepare learners for managing mistake-making progressively and that escape rooms can provide a way to facilitate learning through failure. We first present an original model of failure-based learning that explores why being able to make mistakes safely is important for students and why the use of escape rooms in Higher Education presents an excellent opportunity for the application of this model. We then show the relevance of this model by using it to analyse two case studies that explore different ways in which educational escape rooms can be used in Higher Education: either designed to facilitate learning by *playing* a game; or supporting learning through *designing* a game. Our model of failure-based learning has three stages, emphasising the importance of *preparation*, an iterative *play* cycle of testing, failing, reflecting, and revising, and finishing with a *presentation* phase. The article concludes by considering the limitations of educational escape rooms in this context and highlighting some practical considerations for the use of these approaches.

Key words: Failure, Escape rooms, Play, Games, Playful learning

1. Introduction

Escape rooms, in which small groups work together to solve puzzles within time constraints, have seen phenomenal growth as a recreational phenomenon over the past ten years (Lama and Martín, 2021). Their potential for supporting learning and engagement was quickly recognised by the educational community and the use of educational escape games in Higher Education has also grown quickly, with a wide variety of uses including student recruitment, induction, information literacy, design skills, domain-specific skills and knowledge, and generic skills (Veldkamp, et al., 2020b).

While research on educational escape rooms typically recognises their potential for providing motivational team-based challenges, there is less exploration of the theoretical underpinnings of the approach from a pedagogic perspective. Escape rooms are active learning environments that support authentic (Brookes and Moseley, 2012), problem-based (Savery and Duffy, 1995), and collaborative (McConnell, 2006) learning. Using the theoretical framing of the magic circle (Huizinga, 1955; Salen and Zimmerman, 2004), escape rooms can be viewed pedagogically as playgrounds in which the players suspend disbelief in a narrative separate from the real world, in which it is safe (if not inevitable) for participants to make mistakes and learn from them as they attempt to escape.

Games, by their very nature as intrinsically motivated activities, have evolved to keep players engaged in the game as their experience is balanced between the appropriate levels of challenge and competence (Schell, 2008); too easy and they become boring, too hard and they become frustrating. Failing, and learning from failure, is fundamental to game design, entirely in opposition to the way that failure is villainised and feared in Higher Education (Choi, 2021). Failure in games has two features that make it progressive: first, a game failure seldom has a serious consequence, it might lead to restarting a level or losing resources or a life, but it is unlikely to require starting again from the beginning; second, the failure provides feedback that leads to new knowledge, enabling players to learn from the failure, and avoid it in subsequent plays. Compare this to our education system: failure is seldom seen as positive part of the learning process and high stakes single-shot assessments, such as end-of-year examinations, offer serious consequences with little in the way of useful and timely feedback. The use of high-pressure assessments increases student fear of failure and anxiety, and in consequence decreases risk-taking and innovation. Too often the consequences of failure are too great, and the feedback too little. It is little wonder that students fear failure.

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In this article, we explore the theorisation of escape rooms as failure-based learning environments. First, we provide background on escape rooms and the different approaches to their use in education, before exploring the role of failure in learning. We then present a model of failure-based learning and apply this model to two case studies of escape rooms in education: one where students learn from *playing* escape rooms, and one where they learn from *building* escape rooms and having others play them. Finally, we conclude by reflecting on some of the lessons learned through our use of the model and highlight some future directions for research.

2. Educational Escape Rooms

Worldwide, recreational escape rooms have been growing exponentially in popularity since their inception, with an estimated global market growth from $7.9 billion in 2022 to $31.0 billion in 2032 (Allied Market Research, 2023). They are now a cornerstone of popular culture, increasingly becoming a significant and profitable part of the leisure market with increasing interest in their pedagogic use (Stone, 2016) as they can in many cases be easily aligned with curriculum goals and active learning practices, as well as provide motivating and authentic opportunities for collaboration.

Escape rooms are immersive themed environments in which a player or team of players solve puzzles, discover clues and accomplish tasks to achieve a specific goal, usually within a limited amount of time (Nicholson, 2015; O'Brien and Farrow, 2020). They evolved from single-player digital point-and-click escape-the-room games to being developed as real-world spaces and subsequently being developed to use in classroom environments. In the first iterations of these games, the mission was usually to 'escape' from a room in a limited time, however the educational adaptation of such activities sees the intention change according to the context in which they are used, to align with learning objectives (Veldkamp, et al., 2020a).

From an educational perspective, escape rooms (as well as escape boxes and escape games) align well with active, experiential learning opportunities that enable students to be immersed in their learning. Recent years have seen educators adopt escape rooms (both physical and virtual) into their curricula in a variety of contexts including skill development such as critical thinking, communication and problem solving (Wilby and Kremer, 2020; Avargil, Shwartz and Zemel, 2021), as well as domain knowledge and skills in subjects including medicine and allied areas (Gómez-Urquiza, et al., 2019; Wilby and Kremer, 2020; Rodríguez-Ferrer, et al., 2022), pharmacology (Hermanns, et al., 2017), genetics (Brady and Andersen, 2021), and software engineering (Gordillo, et al., 2020).

In understanding the pedagogic basis for escape rooms, it is important to recognise that their interdisciplinary nature and their origins as a commercial entertainment form means that the language used to describe their educational potential is not always consistent. It does, however, predominantly draw on discourses of learning that is active, gamified, and game-based. Escape rooms are learner-centred active learning opportunities (Adams, et al., 2018) that develop communication and teamworking skills (Veldkamp, et al., 2020a). They can also be considered as gamified systems, which add game mechanics to non-game activities through rewards and points (Deterding, et al., 2011) to increase motivation, add structure and rewards to learning activities (López-Belmonte, et al., 2020), and improve learning outcomes. Although the use of gamification has mixed results and is not without its critics, Brady and Andresen (2021) argue that proper implementation can result in effective escape rooms that increase engagement and motivation for learning.

In addition, escape room pedagogy draws on the literature of game-based learning, which learning seeks to use educational games, either digital or traditional, to teach curriculum content, skills, attitudes, behaviours as well as engage or motivate learners. Promoting learning opportunities by incorporating games into the curriculum has the potential to increase participation of learners who may not have previously engaged (de Freitas, 2006), increase motivation (Deterding, et al., 2011), support experiential learning (Whitton, 2007; Strickland and Kaylor, 2016), and build player agency and well-being (Barr and Copeland-Stewart, 2022). Game designers such as McGonical (2011), Koster (2005), and Schell (2008) reflect on the enjoyment of games as deriving from the process of learning, which is also reflective of the work of Gee (2003; 2007) who considers games as transformative teaching opportunities that provide ways of motivating learners in ways that traditional education does not. However, digital game-based learning has been critiqued for prohibitive costs, complex authoring, long development timelines, and implementation challenges (Begg, 2008; Whitton, 2012; Dichev and Dicheva, 2017) and escape rooms offer a cost-effective approach that overcomes these issues to some extent.

Reflecting on whether games are effective learning tools, de Freitas (2018) argues that research findings point toward significant improvements learning in games over traditional methods, and these are further enhanced by blended approaches that use game and face-to-face approaches. However, establishing efficacy of learning is a complex task that must be contextualised within a wider understanding of how learning happens. Using games does not guarantee a student will be more engaged, motivated, or produced improved learning outcomes.

As well as drawing on the literatures of game-based pedagogy, escape rooms can also be theorised as playful learning environments in which players are intrinsically motivated to collaborate safely, imagine possibilities, take risks, step out of their comfort zones, and – crucially – learn by making mistakes and reflecting on them to move forward. This model of failure-based learning through play is explored in detail in the sections that follow.

3. Failure-Based Learning Through Play

Failure is an inevitable part of life and yet at our schools and universities failure is primarily constructed as something that should be avoided rather than an experience that can be learned from productively. As a result, many students come to university never having experienced significant failure and not having the resources and resilience to deal with it when it does happen. Moreover, the emphasis placed on one-shot, high-stakes assessment leads to an understandable fear of failure among many students. Fear of failure in education can manifest itself in a variety of ways, including avoidance of tasks that might potentially be failed, feelings of shame and personal embarrassment, self-handicapping through activities that remove responsibility for failure such as getting too little sleep or using harmful substances, and learned helplessness, where students perceive that they have little control over their personal situations (Choi, 2021).

Learning how to fail well is a crucial life skill. Self-awareness relating to managing failure is likely to result in a confident individual who is more open to risk taking, and it is only through measured risk-taking that creativity and innovation happens. Failure-based learning is an approach that aims to support students in learning through their failures, supporting both the learning process and building resilience to manage failure itself. Darabi and colleagues (2018) identify five theoretical perspectives that underpin failure-based learning: cognitive disequilibrium where learners strive to update their mental models as a result of failure (Piaget, 1952); impasse-driven learning where failure encourages learners to overcome the impasse causing them to try again by seeking help (VanLehn, 1988); productive failure where students are supported in attempting to provide multiple solutions to difficult tasks (Kapur and Rummel, 2012); failure-driven memory where learners deliberately explain and understand how failure occurred to learn through deliberate practice (Ericsson, Krampe and Tesch-Römer, 1993); and the theory of negative knowledge where non-viable knowledge is seen as beneficial because it leads learners to a more comprehensive understanding of a topic (Gartmeier, et al., 2008).

While there are few studies that investigate failure as a learning strategy, a meta-analysis on learning with both children and adults by Darabi and colleagues (2018) showed moderately positive effects from the approach. Other researchers have found negative effects, such as Eskreis-Winkler and Fishbach (2019) who found in five studies that students learned less with failure, which they argue is because failure is ego-threatening; there is also evidence that failure can lead to decreased confidence (Jackson, et al., 2022). This serves to highlight the importance of the development of safe and collaborative communities of learning in which failure is seen as positive and does not negatively impact on confidence or wellbeing; supporting the development of the magic circle that underpins the value of playful learning.

The use of playful learning approaches is growing in Higher Education (James, 2022). These approaches encompass a suite of playful tools such as games and toys, techniques such as role play or quest-based learning, and tactics such as storytelling or surprise (Whitton, 2018). In addition, playful learning adopts a philosophical position that is exemplified in its signature pedagogy as learning that is open and democratic, accepting of risk and failure, in which learners are intrinsically motivated to enter into the spirit of play (Nørgård, Toft-Nielsen and Whitton, 2017).

The theoretical framing of the magic circle (Huizinga, 1955; Salen and Zimmerman, 2004; Remmele and Whitton, 2014) is useful for understanding the theoretical relationship between play and failure. The magic circle is a mutually constructed space, in which a game is played, which may be signified by objects (e.g., a chess set or a football pitch), may be implicitly constructed by the players (e.g., games of house, banter), or set out as immovable rules of play (e.g., in a video game). By playing a game, players voluntarily agree to abide by the rules of the magic circle and in so doing this means that there are limited consequences of the game in the real world, although it would be impossible to remove these entirely. Magic circles provide spaces for players to imagine possibilities and explore other worlds from within the alternative possibility space of the game. Games are not designed to be easy, but to engage players by keeping them in a state of flow where increasing challenges meet increasing skills (Schell, 2008) and therefore failure within the magic circle is a natural and expected part of game play. As such, playful learning encompasses learning from failure as an intrinsic part of its design and escape rooms, when considered as a form of playful learning, present ideal opportunities to learn from failure.

Approaches exist for failure-based learning in lectures (Lee, Do-Yeop, Yoon, Cheol-Hwan and Park, Chan-Sik, 2011), within case-based learning (Rong and Choi, 2019), and using failure for learning within the context of art and design (Sawyer, 2019). Tawfik and colleagues (2015) present a unified design approach to failure-based learning that highlights four principles that can be used to design learning environments that support learning from failure: 1) allow learners to identify and redefine conditions for success and failure; 2) design the learning environment to intentionally cause students to encounter failure; 3) support reflection on failure; and 4) support solution generation to resolve failures. However, we could find no model published that explicitly links failure-based learning and playful learning, and this is what we present here.

3.1 A Model of Failure-Based Learning

This original model of failure-based learning was a developed during the first two years of a project that explored how the creation of escape rooms could be used to support experiential and collaborative learning for high school students (described in Whitton, 2018). The *EduScapes* project, which ran from 2016-18 supported groups of senior high school students (aged 17-18 years) to iteratively develop escape rooms as a school enrichment project. These rooms were subsequently played live for delegates at a national education conference. In the first two years of the project, twelve students took part each year with three escape rooms developed during a two- or one-week block after the school exam period. In the final year of the project, we expanded the programme with forty students taking part over a six-month period to develop eight different escape rooms.

Ethical approval was granted through Manchester Metropolitan University to undertake focus groups with each of the student groups, and interviews with teaching staff, which were carried out by an independent researcher. Group interviews were transcribed and analysed using thematic analysis (Braun and Clarke, 2006) to better understand the students experience of involvement in the project and explore how to scaffold failure during the game development process so that students saw it as productive rather than negative. The model of failure-based learning presented here emerged from the data analysed during the first year of project and was refined and tested in the second year. The expanded version of the programme is used as one of two case studies in the following section that demonstrate how this model for failure-based learning might be applied to both playing and building educational escape rooms.

Bringing together the student and staff experience data with the reflections of the project team and the literature on designing productive failure in education, we developed and refined an original model for designing failure-based learning (see Figure 1). This model describes iterative cycle of play through testing, failing, reflecting and revising preceded by a preparation activity and followed by a presentation activity. While it was derived from an escape room design project and we apply the model to escape rooms in this article, we also hypothesise that it could be more widely applicable to the design of any failure-based learning experience.

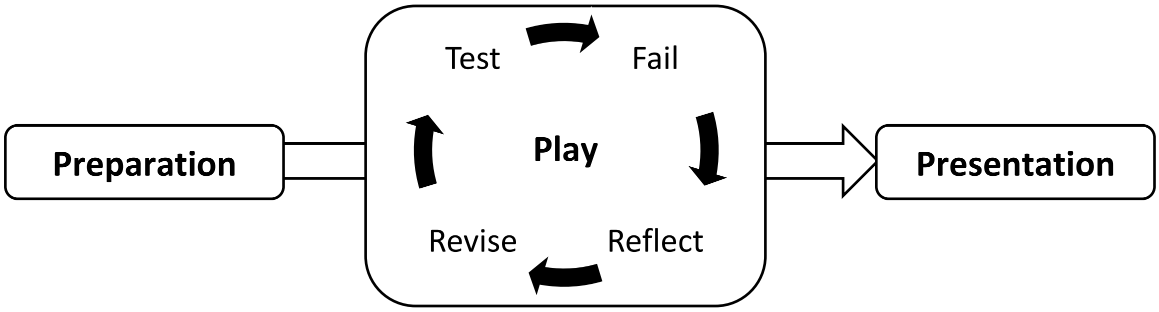

Figure 1: Model for failure-based learning

The model consists of three phases: preparation, play, and presentation. In the **preparation** phase, students are introduced to the idea of games and their benefits for learning. In the case of escape rooms, this can involve learning what escape rooms are and how they work, playing an actual escape room, undertaking puzzles, or other initiation activities that both introduce the idea of an escape room and support students to work in teams and trust one another. This phase is important as it signifies an initial movement into the magic circle and development of the trust and group bonding that makes failure safer.

The **play** phase is the longest in this model, and it is in this phase that ideas are generated and tested, through an iterative cycle of developing and testing propositions, inevitable failure at times, reflecting on those failures, revising ideas, and then testing again. In this phase game mechanics such as scaffolding, gradual increases in difficulty, or hints and clues can be used as learners grow used to learning from failure.

The final phase of the model is the **presentation** phase in which the outcomes of play, learning, or development are presented and reflected upon. The final reflection is crucial to learning from failure because it presents the experience as a positive one for learning, even if the outcomes of play are not in themselves successes.

What is important to consider in this model is the way in which the Preparation and Presentation phases provide entry and exit points to the magic circle of play, similar to the briefing and debriefing that is key to game-based learning (Crookall, 2010). Often, when playful learning or game-based learning is used, too little attention is given to how to remove the initial barriers to play at entry point or how to enhance learning and reflection at the exit point through thoughtful conversation initiation and closure activities. These phases are important for mitigating any impacts of the game play subsequently in the real world, maintaining the sanctity of the magic circle as a separate space.

4. Failure-Based Learning in Educational Escape Rooms

We assume reality is a social construct and understandings of the world cannot be truly objective, but that meaning is continually constructed individually, and shared understandings can be reached through discussion with others to understand their personal interactions with their environment (Coe, et al., 2017). From this, we understand it is the role of the researchers to make sense of these multiple perspectives through interpretive analysis. To remain consistent with the outlined epistemological position, case studies were used to address the following research question: how can the model for failure-based learning in educational escape rooms be applied in a learning context?

In this section, we present two case studies showing different ways in which escape rooms have been used in education and show how the model presented can be applied to support learners to fail progressively and learn through failure in each case. Using a case-based approach enabled us to generate an in-depth, multi-faceted understanding of how this model worked in different educational contexts with two specific and distinct groups (Crowe, et al., 2011).

The first case study explores an example of using escape rooms to teach curriculum content, in this case learning about the potential of escape rooms for learning by playing escape rooms. The second takes a different approach by exploring the potential of learning through failure in escape rooms but facilitating students making the rooms themselves and the game design process that underpins it.

4.1 Case Study 1: Learning by *Playing* Escape Rooms

This case study explores a 'puzzle design in the classroom' workshop that follows the model for failure-based learning with escape rooms by demonstrating escape rooms as frameworks for productive failure. This workshop ran three times between 2021-2023. Participants were teaching staff from Durham University. The first workshop had 14 participants, the second iteration had 12 participants and the third iteration had 25 participants. Ethical approval for study of this workshop was granted by Durham University and participants consented to artefacts they produced being used as part of this case study.

The puzzle workshop was delivered synchronously online over two hours and took the following format:

- Pre-work (preparation phase);
- 20 minutes introduction to literature and briefing (preparation phase);
- 60 minutes escape room (play phase);
- 40 minutes debriefing (play moving into presentation phase);
- Post-workshop reflective activity (presentation phase).

Preparation: This course teaches *about* escape rooms, *using* escape rooms. Engaging participants in the preparation phase lays the groundwork for groups to build trust and prepare to work together, which is an important first step in reducing barriers to enter the magic circle. The escape room is used as an object to think with and deconstruct in relation to failure, which can be helpful to support participants in moving between conceptual areas of difficulty. They also provide a mutual language to understand and communicate decision making, problem solving and failure, both within the game and broadening out to a learning context. This is the 'so what?' stage.

The pre-work involves participants reading a paper that positions the session within literature and introduces the theoretical concept of the magic circle (Huizinga, 1955; Salen and Zimmerman, 2003). Participants are asked to suspend their disbelief and immerse themselves in the spirit of play, or adopt a 'lusory attitude' (Suits, 1978) for the duration of the workshop. The groupwork starts as soon as participants join the synchronous workshop where they are assigned to an exploration group. Through guided discussion and planned activities, groups get to know each other before starting activities. To alleviate pressure on play and recognise peoples' different levels of comfort and preference relating to playing and participation (Whitton, 2010), participants choose their level of involvement and their own adventure. They are encouraged to work collaboratively to choose or devise 'roles' (e.g. playing with pre-prepared escape rooms, designing puzzles, exploring literature, and observing and reflecting on practice). Easing pressure on 'playing' makes the preparation phase more inclusive, enabling groups to enter the magic circle and feel more comfortable with failure.

Enabling participants to find their own paths and explore personal curiosities has been key to encouraging productive failure as we have found that participants are more likely to try and fail if they perceive they are in a safe space to do so. We also found evidence that this supports participants in determining which approach works best for their practice and connecting the two (Brady and Andersen, 2021). For example, one participant reflected that:

> *"This magic circle made a safe space and increased motivation for team working in our group. After experiencing this myself, I overcame the fear of stepping outside of my comfort zone and decided to let my students manage an important part of their module. My students were extremely engaged and excited to be involved."*

Play: An effective way of working through difficult real-world concepts is by experiencing them, with opportunities to reflect on, discuss and contextualise experiences. Using this approach to introduce escape rooms and failure encourages active involvement in, design of and playing with ideas. To allow and support this, one third of the session is dedicated to guided debriefing.

During this phase, participants attempted a pre-planned escape room with a brief that introduces the narrative of the escape room and positions it as an activity without a solution. Their task is then to figure out which puzzle is unsolvable and correctly identifying the puzzle results participants progressing. Participants worked in online breakout rooms so that they could navigate the online activity and have access to workshop facilitators. They were advised to call on facilitators for clues or hints.

Participants then had sixty minutes to work through an online escape room in their groups. The escape room was made up of different types of puzzles, starting with a puzzle to relate the content to literature (e.g., this puzzle used a playful learning article, participants solved clues which led them to the word 'lusory', which unlocked the next activity). Such activities encouraged group cohesion and confidence using the online system and moving through a range of textual, hidden object, and logic puzzles that contained the information needed to meet the workshop learning outcomes. There are prompts throughout for groups to discuss different approaches to problem solving, and failure, exiting and entering the magic circle as they progress and their confidence in failure progresses.

Solving puzzles unlocks information relating to escape room design and the final capstone puzzle challenged participants to put into practice what they have experienced during the game, developing their own puzzle (with extra points for involving failure). Participants highlighted the impact of learning to fail on their own classroom practices, for example:

> *"Since experiencing failure through an escape room I've felt confident to try similar [ones] in the classroom. Students said the discussion was the most valuable part of the module and ask to repeat it."*

Presentation: The final third of the synchronous workshop was used for the presentation phase, where participants shared the outcomes of play, learning and development. The first part of the discussion was scaffolded around failure and positively framed this experience within the activity. The second part was for sharing the results of the puzzle design, again positioning within failure-based-learning and exploring the participants' experiences of the activity.

During the workshop, participants initially struggled to get to the point of revising puzzles, instead using their time to discuss failure and future practice. So, to better support this part of the model we implemented a follow up meeting for playtesting puzzles and getting peer feedback. We discovered that workshop participants sometimes take time to appreciate the value of testing and refinement, but eventually see the value for themselves and for their own participants, for example:

> *"After playtesting my idea with colleagues, I used a social psychology crossword puzzle with my students. The students fed back that they liked that the activity made them feel capable."*

The use of failure-based learning with escape rooms has enabled us to frame discussions around failure in a positive and productive way, while situating it in personal experience and encouraging participants to actively reflect immediately afterwards. For the most part, participants reported this as a valuable opportunity to think about their practice and how this might be useful in other contexts, as well as reporting feeling more confident. Even those participants who remain sceptical leave the workshop having experienced failure in a safe way, and we hope that at the very least we have opened their minds to the possibility of progressive failure as part of the learning process. In the words of one participant:

> *"I'm interested in puzzles and failure but felt very ill equipped to implement anything like it. I struggled to see how it would work in my field. Having spent time reading, attending the workshop, and trying things out, I've come to realise these concepts can be applied to anything. It's about thinking creatively."*

4.2 Case Study 2: Learning by Designing Escape Rooms

Many examples of the use of escape rooms in the literature provide evidence of the efficacy for teaching students in the context of game play (e.g. Alonso and Schroder, 2020; Moore and Campbell, 2021; Wilby and Kremmer, 2020) but there is also a compelling literature that game-making is a valuable approach (Earp, 2015). Perhaps unsurprisingly, it is an approach most commonly used in computing (Wu, et al., 2009; Xinogalos, 2018; e.g. Santana-Mancilla, et al., 2019) and has also been used in non-digital disciplines, for example to facilitate idea generation and creativity (Triantafyllakos, Palaigeorgiou and Tsoukalas, 2011), teaching information literacy (Frydenberg, 2015), sustainable behaviours (Mercer, et al., 2017), and social class and inequality (Sandoz, 2016).

During the final year of the *EduScapes* project outlined earlier, forty students volunteered for the project during which the developed model of failure-based learning was tested over a six-month period during which eight escape rooms were developed and run in a public space.

Preparation: Many students who took part did not know each other before the project started, so the preparation phase had three aims: first, to introduce students to the concept of escape rooms and build understanding on designing them; second, to act as an induction for students to meet and better get to know each other before they started working together; and third, to demonstrate some playful techniques that would help students learn and collaborate throughout the project.

There were four stages to the preparation activities, taking place over two days, which are described in greater detail by Woolley (2019). This extensive preparation process was important both for scene setting and team cohesion. These stages were:

1. Developing understanding of puzzle typology in a collaborative quiz and workshop.
2. Experiencing an *EduScapes* room from a previous student cohort, showing what can be achieved over a relatively short period of time on a small budget.
3. Understanding critical paths for escape rooms using examples to unpick and explore, particularly focusing on what worked and what could be improved.
4. Experiencing a commercial escape room in final teams, supporting both the application of knowledge already gained and further teambuilding.

This stage of the process was appreciated by students for building trust and allowing them to feel comfortable with the task and each other in an environment where mistakes were inevitable.

Play: After the preparation phase, students independently began the process of designing and creating their escape rooms through an extended process of design, test, fail, reflect, and refine as described in Figure 1. Broadly speaking, students were encouraged to carry out their developments in three stages once they had agreed upon the overall theme and the critical path for puzzles. First, they were expected to prototype individual puzzles on each other and outside of the group. Second, they were asked to combine all the puzzles into a 'paper prototype' version of the complete room, for playtesting with other groups and peers. At this stage, escape room experts from the university also tested and gave feedback on the rooms. Finally, the groups could use their small budget to purchase and assemble the final kit required such as locked boxes, padlocks, and theme props, and the completed rooms were given a final test by peers, teachers, and parents. In total, students were expected to have their rooms tested a minimum of ten times over the development period, with each test leading to further refinements.

The focus group data highlighted a range of skills that students believed they had learned from involvement in the project. These included expected areas such as teamwork, time management, planning, organisation, problem-solving, creativity, initiative, flexibility, and independent learning. There was also evidence that the students valued the iterative design process of learning through failure:

> *"… you've kind of just got to get stuck in, make something, test it, and if it doesn't work, change it."*

> *"… it kind of gives you the skills of when something doesn't work, not just giving up but trying to find a solution."*

> *"… to keep refining something and improving it because there were a lot of flaws, a lot of things that could be made better. There are always things that can be done better with it and by doing the Escape Room and having other people test it, then you can really make it better."*

Another unexpected area was highlighted by several students. They described the importance of learning about different ways people engaged with puzzles and played while in the room, which they identified as a key learning outcome. For example, students said:

> *"You think people are going to think one way, but you can't really predict what everyone's going to think or do. What you think they're going to do may not be right because people think differently."*

> *"I learnt that not everyone will think the same way, some people will think of things you didn't think anyone could actually think of and you have to adjust for that when making it."*

Related to this was the joy that students found in watching others – particularly teachers – struggle with puzzles that they had created.

> *"When you watch people do it and you know all the answers, it's, kind of, the frustration and the humour side of it. We were laughing at them. It's the frustrating side of you knowing they are looking for the right thing and then they go off on the wrong track. It's trying to lead them back on the track with the hints and stuff. That was probably my favourite part of it."*

The process of creating rooms that other people could not solve easily increased students' confidence, and seeing teachers fail in their rooms changed the way that several thought about the dynamic between teacher and student.

Presentation: In the final stage of the model, each student team was asked to run their escape rooms for a live audience of conference delegates at the Playful Learning Conference in Manchester. The delegates were a friendly group with a high awareness of escape rooms, which reduced the pressure on students, but they were still expected to deliver a professional product.

At the end of the day, students were asked to reflect in their groups on what they had learned during focus groups. Sharing their finished products with the 'public' proved to be one of the most important aspects of the project for many:

> *"When it all comes together and you see someone do the room and it actually fully works, I think that is really satisfying."*

> *"You see everything that you've conceptualised and discussed and tested finally come together and they are enjoying it and having a good time, which is the most important thing."*

By providing a real-world opportunity for students to present their creations we were, in a way, providing a type of authentic formative assessment, but without the pressure of high stakes grading or one-shot outcome.

5. Conclusions

Students often come to university without experience of failure or the resilience to deal with failure when it happens. Learning how to fail and manage failure is a crucial skill that supports risk-taking, problem-solving and leads to innovation. We can learn from the way failure is handled in games and use this to better support productive failure in educational contexts. Escape rooms as a form of play can provide a framework for learning about failure through tools, techniques, and tactics such as: clear goals and narrative, a requirement for problem-solving and lateral thinking and surprise.

However, using escape rooms in learning is not without challenges. For example, playing, and failing, is not something that appeals to everybody. For those who choose to play, they may not enter the magic circle as intended but instead focus on cheating or be overly competitive and winning. Using games in education can be a difficult balancing act between incorporating game elements and fun, while also retaining the purpose of the educational context. The wrong balance could misalign or skew the activity, shifting the emphasis away from learning.

Inadequate briefing or debriefing around failure could potentially result in low-confidence, ego-driven engagement, or frustration from players. To counter challenges, we believe it is important to take time during the preparation phase to develop a safe collaborative community of learning from the outset of activities, in which failure is framed as a positive outcome, and does not negatively impact on confidence and wellbeing. This may be achieved by following the preparation, play, presentation model outlined in Figure 1 and retaining the importance of briefing and debriefing in such activities. As demonstrated in both case studies, different applications result in different challenges and outcomes, however both lead to opportunities to problem solve resulting in authentic learning without the pressure of high stakes grading.

The model we propose has power in its simplicity. It centres on the importance of the magic circle, a mutually constructed safe space that mediates the relationship between play, and failure in a supported space. It constructs the escape room as a framework for learning from play as well as a safe space to learn from failure. The three stages of preparation, play, and presentation open gateways in to and out of the magic circle of play, removing initial barriers to play at entry points, opening different options and ways in which learners can engage, and enhancing learning and reflection at exit points through thoughtful conversation and closure activities.

This model can potentially provide a pedagogic framework for educators using escape rooms as part of their practice, as well as those who want to think more broadly about supporting learning through failure by explicitly considering how to provide opportunities to make mistakes productively. While this model has been developed in the context of escape rooms, a future direction for research would be the applicability of this framework more generally to other forms of pedagogy, embedding the benefits of failure-based learning more widely into curricula and supporting students to fail, take risks, innovate – and have fun while they do.

Ethics statement

All participants gave their informed consent for inclusion before their information was included in the case studies described.

Case study 1: Durham University DCAD-2023-06-15T16_09_02-kfqn12

Case study 2: Manchester Metropolitan University ED-1718-17

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Design and Implementation of Interactive, Remote Online Escape Rooms in Medicinal Chemistry

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Abstract: This research explores the development, execution, and student feedback on a multi-themed digital escape room (ER) activity, designed for teaching medicinal chemistry during the COVID-19 pandemic. It aimed to examine students' perceptions of the ER activity, focusing on its effectiveness in enriching students' understanding of medicinal chemistry and increasing their engagement level. Implemented in a synchronous online lecture for third-year pharmacy students, this ER activity was designed with the intention of fostering active learning and teamwork. A total of 184 students participated in various medicinal chemistry-themed challenges, using puzzles on a virtual whiteboard and breakout rooms for team discussions. The findings gathered from the post-implementation survey highlight the impactful learning outcomes associated with a replicable ER activity designed for online medicinal chemistry courses. This innovative teaching strategy not only cultivated a deeper understanding of key medicinal topics among students (mean=4.36) but also enhanced their collaborative skills through increased peer interaction (mean=3.73). They also reported higher level of engagement due to the interesting activities (mean=4.53). The quantitative results were affirmed by the qualitative feedback obtained from the open-ended questions, indicating a consistently positive learning experience and student reception towards the ER implementation. Although they encountered obstacles like stress, internet issues, and unfamiliarity with the ER format, more than 70% of the students agreed that the ER activity was a highly effective learning tool. This digital ER activity also demonstrates promise as an educational tool to encourage active learning and enhance students' motivation in learning medicinal chemistry. The study has showcased the potential benefits of integrating digital ERs into traditional teaching methods, especially for catering to the preferences of Generation Z students in a collaborative learning environment. In addition, the research offers valuable insights into the use of ERs in pharmacy education, contributing to the scarce literature on ER applications in medicinal chemistry and opening avenues for further research on ER-based educational strategies.

Keywords: Active learning, Educational games, Escape room, Medicinal chemistry, Gamification

1. Introduction

In the current higher education landscape, undergraduates, primarily from Generation Z (Gen Z), are navigating their studies amidst a digital revolution that has gained momentum in the post-COVID-19 era. This generation is characterised by a seamless integration of digital technologies into their daily lives, effectively erasing the boundaries between physical and digital spaces and embracing what is known as a 'physical' reality (Prensky, 2001 & 2002; Mele et al., 2023; Poliakova et al., 2022 & 2023). Their modes of communication, collaboration, and personal management are deeply entwined with social media, the internet, and various digital devices (World Economic Forum, 2020). Thanks to the internet, they have access to a vast amount of learning materials and resources at their fingertips (Sadjadi, 2023; Tolstikova et al., 2023).

Studies have outlined characteristics of Gen Z for the higher education sector; they are self-starters with the willingness to learn on their own from online courses, goal-oriented, avid virtual gamers, and prefer to design their own studies (Schwieger and Ladwig, 2018; Tolstikova et al., 2022 & 2023). The changing demographics and characteristics of students in the higher education institutions call for innovations that prepare students for uncertain and ambiguous future (Azer, 2008; Eckleberry-Hunt et al., 2018; Sadjadi, 2023; Tolstikova et al., 2023). Crucial are adaptive and dynamic curriculum incorporating teaching practices and innovations that foster active learning and inculcate critical thinking through collaborative learning.

During the COVID-19 pandemic, the abrupt shift to online distance learning in universities, necessitated by the closure of higher education institutions, brought significant changes in teaching methodologies. This period saw a predominant reliance on synchronous lectures and video presentations, often delivered through PowerPoint. Despite their widespread use, these methods, which closely resembled traditional lectures, faced criticism for

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their lack of engagement and effectiveness. A study by Baker et al. (2018) highlighted this issue, finding that PowerPoint lectures had no significant impact on improving learning outcomes compared to the conventional chalk-and-talk approach. Doherty (2007) also pointed out that such online instruction methods led to lower student attendance, diminished peer interactions, and fostered a passive learning environment. In large enrolment programs, particularly in disciplines like medicine and pharmacy, traditional lecture formats continued to be the preferred instructional strategy due to their perceived efficiency and cost-effectiveness. However, this approach proved to be especially challenging in courses like organic chemistry, medicinal chemistry, and pharmacy ethics. Studies by Cain (2019) and Abdul Rahim et al. (2022) revealed that students often perceived these courses as lacking immediate practical application or relevance to their future roles as pharmacists.

Furthermore, traditional lectures encourage a strong dependency on the lecturer, and not the students. It hardly provides the conditions in learning that would prepare students the autonomy, agency and promotes peer interdependence in dealing with uncertainty in simulated or authentic learning environments. Educational games are a notable innovative pedagogy that has gained widespread attention in the recent years (Kabilan, Annamalai and Chuah, 2023; Zainuddin et al., 2020). It is a type of instructional strategy in which students are the active participant in a competitive learning activity that is governed by a set of rules. Students benefit by learning in a fun and interesting environment in which the repercussions of errors are minimised. An educational game that has become increasingly popular in amongst the younger generations is escape rooms (ERs) (Abdul Rahim et al., 2022; Rawlinson and Whitton, 2023; Veldkamp et al, 2020).

ERs are time-constrained team-based games that are rooted in active and cooperative learning pedagogy, which empowers student teams to problem-solve tasks and puzzles before escaping a locked room (Brown, Darby and Coronel, 2019). At its core, the use of ERs in teaching and learning embodies the principles of Experiential Learning Theory (Kolb and Kolb, 2017), an instructional theory grounded in a four-stage learning cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Through the interactive nature of ERs, learners directly engage with problems (concrete experience), a dimension that serves to transition abstract concepts into tangible challenges (Morris, 2020). This hands-on interaction permits reflective observation, during which learners analyse the outcomes of their actions within ERs and articulate their findings, initiating a dialogue that enhances collaborative learning (Moseley et al., 2020; Kirschner et al., 2018). Subsequently, this reflection stimulates abstract conceptualisation, inviting learners to formulate hypotheses and devise strategies to address the challenges encountered within the escape room environment. The cycle culminates in active experimentation, whereby these newly synthesized theories are applied to novel puzzles and problems, effectively operationalising learned concepts (Kolb and Kolb, 2017).

Building on the established effectiveness of ER activity in educational settings (Abdul Rahim et al., 2022; Abdul Rahim, 2023; Eukel et al., 2017; Veldkamp et al., 2020), this study examines a specific implementation of ER activities in the context of medicinal chemistry education. The ER format, varying from linear to open or path-based structures, has been shown to effectively sequence puzzles in a way that enhances learning (Nicholson, 2015; Veldkamp et al., 2020). Furthermore, the linear game design, closely aligned with specific instructional strategies (Cain, 2014), along with its application in health sciences, demonstrates its capacity to boost confidence and competence in professional practices and as a preparatory tool for problem-based learning (Abdul Rahim, 2023; Manzano-León et al., 2021; Veldkamp et al., 2020).

However, the unique nature of medicinal chemistry, encompassing complex concepts and requiring a deep understanding of chemical and biological interactions, raises questions about the suitability and efficacy of ERs in this domain. The immersive and thematic approaches of ERs, which engage students in scenarios like solving mysteries or undertaking rescue missions, must be examined for their ability to not only engage students but also to effectively convey complex medicinal chemistry concepts (Abdul Rahim, 2023; Veldkamp et al., 2020). This study, therefore, seeks to investigate the implementation of a multi-themed escape room activity for medicinal chemistry education, particularly as an innovative learning method during the COVID-19 pandemic. The research problem centres on understanding the effectiveness of this ER activity in medicinal chemistry education. Specifically, it aims to address the following research questions:

RQ1:What are the students' perceptions of the ER activity in terms of engagement and learning experience? :

RQ2:How do students perceive the usefulness of the ER activity in enhancing their learning in medicinal chemistry?

2. Literature Review

2.1 Student Engagement in Online Learning

Student engagement in learning, particularly in the context of online and blended learning environments, has been a focal point of educational research, especially during the COVID-19 pandemic. Salas-Pilco et al. (2022) synthesised findings on student engagement in Latin American higher education institutions during the pandemic, emphasizing the behavioural, cognitive, and affective dimensions of engagement (Salas-Pilco et al., 2022). This three-way model of engagement underscores the multifaceted nature of student involvement in learning processes, highlighting the importance of addressing all three dimensions to foster effective learning environments. Unlike traditional classroom settings, online learning environments necessitate active participation and self-directed learning, which can be difficult to sustain without effective engagement strategies. A vast body of research has examined this topic, exploring the multifaceted nature of student engagement in online contexts. Czerkawski and Lyman (2016) emphasised the importance of social engagement, highlighting the need for interaction and collaboration among students and instructors. Understanding these various dimensions allows educators to design online learning experiences that cater to the diverse needs and learning styles of their students. On the other hand, in the study by Abou-Khalil et al. (2021) on low-resource settings, they found that student-content engagement strategies to be most preferred by the participants of their study as compared to student-student strategies. This could be largely due to the limitations of real-time online interaction between students. This theme in the literature showed that although engagement is key in online learning, its implementation remains the major factor affecting the learning experience and intended outcomes.

Another key theme in the literature concerns the factors that influence student engagement. Khlaif et al. (2021) investigates the factors that influence student engagement in online learning environments during the COVID-19 crisis. The study, conducted in middle schools, highlights the negative impact of the transition to online learning on student engagement. Cultural factors, such as parental concerns and traditions, are identified as significant contributors to this phenomenon. The quality of the online content is found to be subpar, further hindering student engagement. The authors emphasise the need for further research to improve online learning in the long term, particularly in the context of cultural and infrastructural challenges faced by developing countries. Furthermore, studies in the areas of student engagement in online settings highlighted the need in establishing clear expectations, providing timely feedback, and creating a supportive learning environment (Carroll et al., 2021; Gray and DiLoreto, 2016).

Nevertheless, in recent years, gamification and game-based learning has emerged as a promising strategy to boost engagement in online programs (Krath, Schürmann and Von Korflesch, 2021). Gamification is the process of incorporating game design elements into non-game contexts to enhance user engagement and motivation. This approach leverages techniques such as point scoring, leaderboards, and rewards to drive participation and improve outcomes in various fields like education, marketing, and workplace productivity (Deterding et al., 2011; Koivisto & Hamari, 2019). Looyestyn et al. (2017) in their systematic review, explore the potential of gamification, dissecting its various features like points, badges, leaderboards, and challenges. It covers the existing research on gamification's efficacy, analysing studies that have employed gamified interventions in online educational settings. The review highlights that gamification can be a powerful tool for enhancing engagement, but further research is necessary to optimise its design and implementation strategies for different contexts and learner populations. One of such gamified strategies in teaching is the use of ERs, which remains largely understudied in higher education especially in the field of medicinal chemistry.

2.2 Escape Rooms for Teaching and Learning

Escape rooms, originally popular as entertainment venues, have recently gained attention in the educational sector as innovative tools for teaching and learning. These immersive, problem-solving environments provide a unique platform for engaging students in active learning, critical thinking, and teamwork. ERs have been regarded as a type of gamification, which incorporates aspects of game design and principles, such as rewards and incentives, to boost user participation and motivation (López Carrillo et al., 2019) Nicholson (2015) explored the educational potential of ERs, highlighting their ability to create a context for learning through play, which can be particularly effective in enhancing student motivation and engagement (Nicholson, 2015). The interactive nature of ERs requires participants to apply knowledge and skills in a practical, hands-on manner, making the learning experience more memorable and impactful. The adaptability of ERs to various educational subjects and levels is another key advantage (Adams et al., 2018). Veldkamp et al. (2020) demonstrated how escape rooms can be tailored to teach specific subjects, ranging from science and mathematics to history and language arts. This flexibility allows educators to design ER scenarios that align with curriculum objectives and learning outcomes (Veldkamp et al., 2020). By incorporating elements of storytelling and thematic challenges, ERs can transform traditional classroom content into an engaging narrative, fostering deeper understanding and retention of the material.

In addition, ERs promote the development of 21st-century skills such as collaboration, communication, and problem-solving. A study by Clarke et al. (2017) found that participants in educational ERs showed significant improvement in teamwork and communication skills, as the nature of the challenges within the rooms necessitates effective collaboration and information sharing among team members (Clarke et al., 2017). This aspect of ERs is particularly valuable in preparing students for real-world scenarios where teamwork and problem-solving are essential. Kinio et al. (2019) also demonstrated that medical students who participated in an ER as part of their curriculum showed increased engagement and motivation compared to traditional learning methods. The study emphasised that the active participation and problem-solving elements in ERs stimulate student interest and involvement, leading to a more engaging learning experience (Kinio et al., 2019). Thus, ERs offer a multifaceted approach to education, combining knowledge acquisition with the development of essential life skills.

Despite the insightful findings from the literature on student engagement in online learning and the educational potential of escape rooms (ERs), several limitations and research gaps remain evident. One notable limitation is the generalisability of these studies, as many are context-specific, focusing on particular regions, educational levels, or subjects, which may not translate well across different educational settings or cultural contexts. For example, studies on student engagement in online learning, particularly in low-resource settings, may not fully capture the engagement strategies in more technologically advanced environments. Moreover, the effectiveness of engagement strategies, including gamification and ERs, in promoting long-term knowledge retention and transferability to real-world scenarios remains underexplored. While studies like those by Looyestyn et al. (2017) and Kinio et al. (2019) highlight the immediate benefits of such approaches in enhancing engagement and motivation, there are still rooms in examining their impact on learning outcomes and skill development beyond the classroom. Another gap is the integration of technology in engagement strategies. With the rapid advancement of digital tools and platforms, there is a need to explore how emerging technologies can be effectively harnessed to enhance engagement in online learning environments.

3. Methodology

3.1 Context of the Study

During the COVID-19 pandemic, a 2-credit hour PHC525 NSAIDs, Gastrointestinal system and Pharmacotherapeutics course was conducted online via synchronous “live lectures”. The course that consists of lectures in physiology, pharmacology, and medicinal chemistry. The integrated course was taught to 184 third-year pharmacy undergraduate students at the Faculty of Pharmacy, Universiti Teknologi MARA (UiTM). Moreover, students were provided with asynchronous teaching materials, e.g., instructional videos, PowerPoint slides, PDF, and end-of-topic assessments throughout the 14-week course.

In week 10, most medicinal topics were delivered asynchronously as short video lectures. The topics were peptic ulcer drugs, anti-emetics, H_1-antagonists, and non-steroidal anti-inflammatory drugs (NSAIDs). Then, in week 13, a 2-hour live lecture session was held for the students. The ER activity was conducted in the first hour of the session, followed by a lecture on the medicinal chemistry of gout. As an educational intervention, the primary purpose of the ER activity was to help students review the earlier topics in medicinal chemistry and improve their understanding of the didactic content presented in the instructional videos (Abdul Rahim et al., 2022; Eukel et al., 2017; Veldkamp et al., 2020). The escape game also served to encourage peer interactions and active learning online with the hope of turning a typical dry synchronous lecture into a more interesting session under the gaming environment.

The study utilised a design-based research methodology to investigate the impact of the ER activity on student engagement and learning experiences. This approach involved a systematic process of analysis, design, and implementation within a practical educational environment (Wang, 2020). This paper primarily reports on the design and development of the educational escape rooms (ER) and the evaluation results following the initial implementation. Central to the research was the development and implementation of an ER challenge named "MedChem," tailored specifically for medicinal chemistry students. This challenge was integrated into synchronous online learning sessions, engaging the students directly in the activity. To assess the effectiveness of the MedChem ER, the researchers used self-reported questionnaires, which were distributed to the students upon the completion of the ER activity. This instrument measured the students' perceptions of the ER challenge, focusing on how it influenced their engagement levels and enhanced their overall learning experience.

3.2 Design and Development of the MedChem Challenge Escape Room

The MedChem Challenge ER featured a combination of interactive quizzes and escape room templates as puzzles. As shown in Figure 1, these puzzles were created using Genially templates, a web-based tool for creating interactive learning content. The game employed a linear game structure; as such, the puzzles were arranged accordingly on a real-time collaborative platform. In our case, the Miro board was chosen for its ease of use and stability for online collaboration. Students would solve the interactive puzzles sequentially starting from themes: 1) Where in the world is?, 2) MedChem Superheroes, 3) Find C-19X vaccine code, 4) Stop the Alien invasion, and 5) Final challenge: Baek-hyun's First Date.

As shown in Figure 1, the board was visually divided into four sections. From left to right are: 1) the ice-breaking (the yellow circle), 2) the game briefing, 3) four escape room puzzles, and 4) the final challenge. Unlike recreational escape rooms, the design of escape rooms for pharmacy students must align with specific learning objectives (Table 1). The ER game helped students review the video lectures posted in week 10 by assessing their understanding of the topics. Designed for the players to progress from one topic to the next, the game design also helped ensure that students remained focused on a topic before moving to the next one.

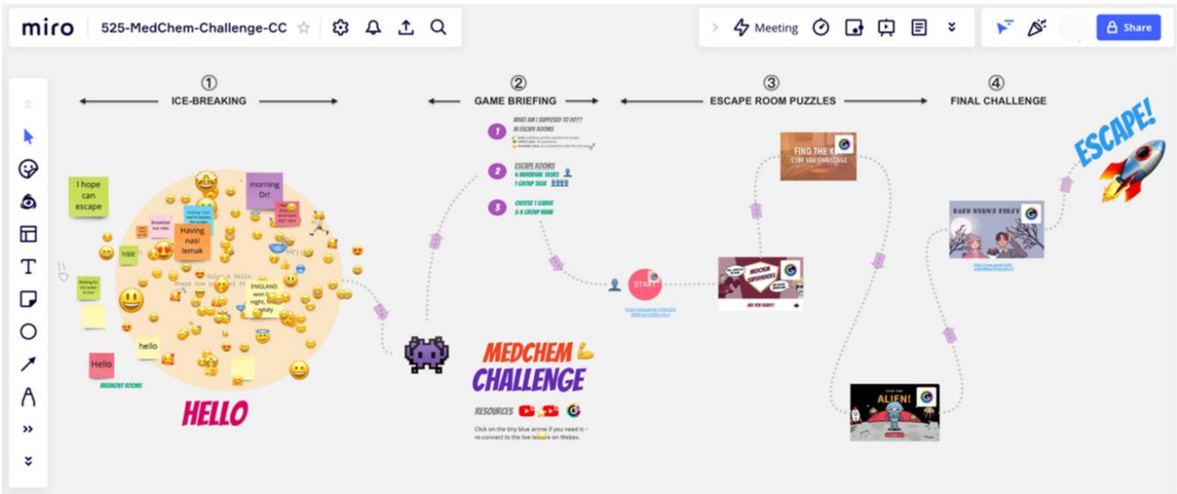

Figure 1: Screenshot of the MedChem Challenge on the Miro Board showing the four sections: 1) ice-breaking area, 2) game briefing, 3) four escape room puzzles, and 4) the final challenge

Furthermore, to keep students engaged with the online tasks, multiple themes were used for each topic, and they were aligned to the course's learning objectives (Table 1). These themes served as the underlying narrative for the challenges. For instance, MedChem Superheroes theme was used for the topic of anti-emetics, whereas Stop the Aliens' invasion theme was created for reviewing peptic ulcer drugs. In the final challenge, Baek-hyun's first date served as a short case-based learning (CBL) for the students to review the medicinal chemistry of H_1 antagonists.

Table 1: Tasks and Learning Objectives

Puzzle	Puzzle Name	Learning Objective and Topic	Type of assessment, Game structure
1	Where in the world is?	A warm-up activity to familiarise students with Genially and the game format.	Quiz, Linear
2	MedChem Superheroes	To briefly review anti-emetics	Quiz, Linear
3	Find the C-19X vaccine code	To review chemistry of NSAIDs	An interactive graphic adventure, Open structure

Puzzle	Puzzle Name	Learning Objective and Topic	Type of assessment, Game structure
4	Stop the Aliens' invasion	To review peptic ulcer drugs	Quiz, Linear
Final challenge	Baek-hyun's First Date	To review H_1 antagonists, then apply their knowledge in a fictitious situation.	Case-based learning

The background story of the final puzzle revolves around Baek-hyun, a pharmacy student in UiTM, who went on the first date with Soo-hee (Figure 2). Soo-hee asked Baek-hyun for some drug information; for instance, she wanted to know the differences in antihistamine drugs and which drug is best to take for her conditions. Trying to impress Soo-hee, Baek-hyun realised that he had to revise the topic on antihistamine drugs before he could answer her questions.

Figure 2: The CBL final puzzle on the medicinal chemistry of H_1 antagonists was presented in the form of a comic strip titled "Baek Hyun's First Date" using a Genially theme

This CBL tapped into the Korean pop (K-pop) culture that is quite popular with Malaysian youth and in Asia. Baek-hyun is a familiar name to the students since it is the name of a South Korean singer-songwriter, an idol to many adoring K-pop fans. Going out on first dates and being asked about drugs are situations that the younger generation of pharmacy students can relate to. Furthermore, the CBL provided an authentic learning context for the students by triggering them to "think like a pharmacist". The third-year student group would need to review given teaching materials and then apply their knowledge in a clinically-relevant scenario of the CBL before providing an answer to Baek-hyun. Unlike the rest of the puzzles in Table 1, the Baek-hyun puzzle was presented as a comic-strip format. Under the 'Gamification' category on the Genially platform, more than 150 interactive templates are available for quizzes, games, and escape rooms. These attractive templates can be easily customised and would save significant time for instructors who are keen on developing a digital ER activity.

In addition to a variety of themes, the puzzles in the MedChem Challenge consisted of quizzes, a graphic adventure (an interactive point and click), and a CBL. These employed a combination of linear and open game structures. As such, the puzzles introduced varying levels of difficulties in the ER activity. For example, puzzle 2 was designed as a sequential multiple-choice quiz. In contrast, an interactive graphic adventure was chosen for puzzle 3 (Find the C-19X vaccine) with an open game structure.

In the open game structure, students have the freedom to search and explore for specific clues hidden in each image. Upon stumbling on a correct area, a question pops up. A correct answer would reveal a clue that could be used to unlock the next puzzle. However, a wrong answer would lead students back to the image and the search for clues starts again. The combination of difficulty levels, elements of surprises and multiple themes in the ER activity was an intentional design element in the digital ER game. It could help maintain students' interests and engagement online via the varied, unexpected, or surprising activities, thus fostering a sense of curiosity and anticipation which could led to more satisfactory learning (Benlahcene, Kaur and Awang-Hashim, 2021). Under the time pressure, they are likely to have little choice but to work together to escape. Ideally, the ER activity would foster peer collaboration during the synchronous lecture session.

4. Implementation of the synchronous 'Escape the MedChem Challenge' Activity

4.1 The Ice-Breaking Session

The 2-hour synchronous session began with an ice-breaking session. When students joined the online Miro Board, they could view the entire ER game. A short ice-breaking session is recommended in any online interactions or courses. To start an ice-breaking session, the instructor posted a message "Share how do you feel this morning" on a huge yellow circle (Figure 1). Almost immediately, the students filled the yellow circle with emojis. Some of the emoticons were happy, surprise, smiling, and love. Sticky notes were also used. Several students said ‘hello’ or ‘good morning Dr’. Others shared their feelings or what they were having for breakfasts.

The ice-breaking session in this online lecture served two purposes: firstly, to get students familiarize with the Miro platform and secondly, to create a sense of community in a remote online lab by getting them share individual feelings and experiences with other students and the instructor (Hagedorn, Serth and Meinel, 2022; Garrison, Anderson and Archer, 1999). Current literature is replete with studies that reported student passivity or lack of interactions in synchronous lectures held during the COVID-19 pandemic (Sadjadi, 2023; Pires, 2022). Many contributing factors were highlighted, including costly data, internet connectivity and lack of skills in online facilitation. Nevertheless, this ice-breaking activity demonstrated the importance of a low-stake activity, i.e., using emoji or sticky notes as a potential substitute for verbal or video at the beginning of an online lecture. Previous studies supported the use of emoji as a catalyst to foster social and teaching presence in online learners through communication, rapport, and perceived authenticity (Bai et al., 2019; Kim et al., 2022).

4.2 The Escape Room Gameplay

Right after the ice-breaking session, a 10-minute briefing was conducted to inform students about the rules and gameplay. The third-year students joined their own groups of 5-6 members, then went into their group breakout rooms in Cisco Webex. They were instructed to begin with the first puzzle (Figure 3). The questions in puzzle 1 were intentionally created to be as simple and straightforward; they served as warm-up questions to get students to familiarise with the Genially platform. When all questions were correctly answered, students would collect the password ‘Belladona’ and use it to access puzzle 2 (Table 1). Google Forms, in quiz mode, was embedded at the end of each Genially puzzle for students to check-in. The forms captured students’ progression as they moved in and out of the digital Genially puzzles during the online ER activity. To escape the MedChem Challenge, the time allocation for the teams was 40 minutes.

Figure 3: The warm-up questions of Puzzle 1 tested students on the origins of certain drugs or compounds with medicinal properties. If they answer all correctly, they would be able to obtain the password (e.g., Belladona) to unlock the next task (Puzzle 2)

The instructor served as the game master and facilitated the ER game online. In a physical ER, the game master can directly monitor students’ dynamics and interactions with puzzles by observing their behaviours in person or via webcams (Abdul Rahim et al., 2022). On the contrary, in an online environment, monitoring students is not possible unless the platform is equipped with a tracking feature. Available on the Miro board, the user cursor tracking feature enabled the game master to monitor students’ movements in real time. Since a student’s cursor is colour-coded and bears the student’s name, it was easy to identify students and locate their whereabouts on the platform. Students could also see their group members’ cursors which may facilitate online peer collaboration. This is one main advantage of using the Miro board during the remote online ER activity.

Another advantage of the cursor tracking feature in the Miro board is that it allows the game master to anticipate potential issues. Technical issues with the platforms, internet connectivity, or ER puzzles are some potential issues that could arise during an online ER activity. A case in point: about halfway through the game, the game master noticed that an estimate of twenty students’ cursors remained stationary for some time around puzzle 3 compared to puzzles 1 and 2. Based on this observation, the game master quickly identified some students from different groups and joined their breakout rooms to make some enquiries. Apparently, they were stuck and unable to find the correct clues in the interactive graphic adventure puzzle 3. The instructor provided hints to facilitate the students’ progression through the puzzle as listed in Table 1.

5. Results and Discussion

Of 184 students, only 100 could attend the synchronous lecture session and participate in the ER activity. Eighty students responded to the survey on a voluntary basis. Seventy-one respondents (89%) were female students, and 9 (11%) were male. This imbalance in gender representation is notable. However, it is important to clarify that the researchers did not influence the enrolment process or the allocation of students to this course. The selection and enrolment at the programme level were conducted centrally by the educational institution. Therefore, the gender distribution observed in this study's participant group reflects broader enrolment trends, rather than any selection bias on the part of the research team. Figure 4 shows the devices used by students during the ER game; 83% of the students used laptop computers to play the game. A small percentage of students (3%) used two devices for the activity.

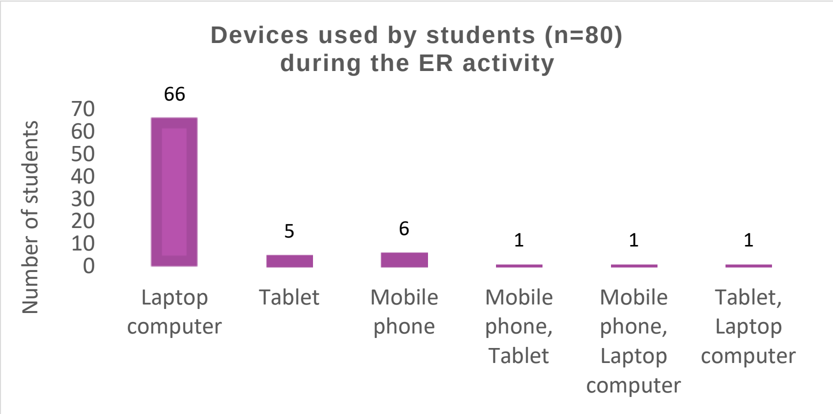

Figure 4: Types of devices used by students during the ER game

5.1 Contribution of the Escape Room Activity in Learning Medicinal Chemistry

Table 2 summarises the results of the student perception of the ER activity. The 15-item questionnaire was adapted from Eukel et al. (2017). It used a five-point Likert scale for each item (1=strongly disagree, 2= disagree, 3=neutral, 4=agree, and 5=strongly agree). Towards the end of the questionnaire, blank spaces were included for students to write further comments and suggest improvements.

Students perceived the ER activity as fun and interesting (4.53), which is consistent with previous studies employing ER games (Abdul Rahim, 2023; Brady and Andersen, 2021; Eukel et al., 2017; Veldkamp et al., 2020). Moreover, they found the ER game relevant to medicinal chemistry topics (4.44). Mostly agreed that the ER activity seemed to be an effective way to learn new information related to medicinal chemistry (4.36), despite having difficulty to focus due to feeling stressed or overwhelmed (3.00). The mixed responses suggested that the ER activity could prove challenging to students, yet they enjoyed it (see Table 4, entry 1). Besides, they thought could learn better in the game format than in a live lecture (3.83) or a video lecture (3.70), and they felt engaged with their group mates to learn new materials (3.73). Fostering teamwork is one advantage of the ER activity and would certainly help them develop the skills as future pharmacists working in multi-disciplinary healthcare teams.

Table 2: Student perceptions on the contribution of the escape room activity in learning medicinal chemistry

Items	*m*	*SD*
The activity was fun and interesting!	4.53	0.94
The escape rooms were relevant to the topics in medicinal chemistry.	4.44	0.95
The escape room was an effective way to learn new information related to medicinal chemistry.	4.36	0.97
I learn better in a game format than in a live lecture.	3.83	1.11
I learn better in a game format than in a video lecture.	3.70	1.05
It was difficult for me to focus on learning because I was feeling stressed or overwhelmed.	3.00	1.20
I feel I was able to engage with my group mates to learn new material.	3.73	1.09

m mean, *SD* standard deviation

5.2 Escape Room Game Design

In terms of the ER game design, getting instant feedback after making mistakes appeared to be well-received by the students (4.50, 0.95) as shown in Table 3. This game feature informed them of their level of understanding of the topics. Students seemed hesitant about the statement on the ER activity being too difficult (2.58, 1.05). Concerning the time frame of the ER game, they gave mixed responses (2.41) on having insufficient time to complete the game. Though the students seemed fairly distracted by the non-educational parts, i.e., the multiple Genially themes in learning medicinal chemistry (3.11, 1.41), the variety of the escape room activities was perceived as an effective way to review the topics in medicinal chemistry (4.36).

Table 3: Student perceptions on the escape room game design

Items	*m*	*SD*
Getting instant feedback after making mistakes makes my learning better.	4.50	0.95
The variety of escape rooms was an effective way to review the topics in medicinal chemistry.	4.36	0.97
Not enough time...	2.41	1.19
The escape rooms were too difficult!	2.58	1.05
The non-educational portions (e.g., the superhero, the alien themes) distracted me from learning about medicinal chemistry.	3.11	1.41

m mean, *SD* standard deviation

5.3 Students' Learning Experiences and Overall Student Perception on the Activity

Table 4 shows an overall student perception of the escape room activity. The third-year student found the ER game challenging yet seemed to enjoy the challenges (4.40, 0.99). It could correspond to the utilisation of a variety of features employed in the ER game in which challenging puzzles serve as a source of enjoyment and excitement in learning. Furthermore, students perceived that the activity would make them more confident in learning medicinal chemistry (3.99, 0.97). They would recommend the ER activity to other students (4.31, 0.98).

Table 4: Overall student perceptions of the escape room activity

Items	*m*	*SD*
Challenging games, but I enjoyed them.	4.40	0.99
The escape room helped me feel more confident learning medicinal chemistry.	3.99	0.97
I would recommend this activity to other students.	4.31	0.98

m mean, *SD* standard deviation

Table 5 lists representative positive and negative students' comments in the open-ended questions. Most students positively perceived the game, and described it as "fun", "interesting" and "exciting" for learning medicinal chemistry topics. A student's comment that illustrates the ER learning experience: "It's exciting way to learn! First time doing this activity and it definitely wake me up from feeling sleepy in the morning." They also found that the game was helpful for learning the Medicinal Chemistry topics since it provided an assessment on their level of understanding and gave instant feedback on their mistakes.

Table 5: Representative students' comments on the ER activity

Positive comments	Negative comments
It's exciting way to learn! First time doing this activity and it definitely wake me up from feeling sleepy in the morning.	More time. before starting the game, ice-breaking with teammates because we did not start together and lost communication :D
This is much interesting to learn! Since we know on what level of understanding we have in Med Chem and we can improve in the future.	It would be better if lecturer could ask students to form group beforehand so we can form group with people that we are comfortable with.
I love this escape room because it gives me better understanding because of feedback given after make mistakes. It would be nice if every after lecture, we play this game to improve understanding.	The activity was fun. But sometimes disrupted with internet connection problem. Because of this problem, certain students might lost and didn't know how to participate in the game. Students need to ensure to have strong internet connection before playing the game.

Positive comments	Negative comments
This is a very interesting way of learning, I can see that lecturer really put a lot of effort for this learning session. I would prefer picture along side with the questions so I can see the chemical structure mentioned.	Actually for me with slow line Internet connection, it was kind of lagging (need to open Webex and Miro in one).
Overall is awesome. Its actually interesting and fun!!!!! Thank you Dr.	This way is good since i know what my mistake are however using Miro made my laptop kind of slow.

Negative comments on the game design highlighted two inter-related technical aspects which were not apparent during the gameplay: 1) the use of the Miro Board, and 2) internet connections. According to some students, the use of the Miro Board caused their computers to slow down. They also reported that the use of multiple platforms (Genially, Cisco Webex and Miro board) caused noticeable delays during the gameplay, thus underscored the need for a good and stable internet connection for such online activity. Another consequence of frequent internet disconnections during the gameplay was that some students could not follow the pre-game briefing. This led to them feeling lost and unable to fully participate in the game. Apart from the technicalities, students also expressed their need for more time before starting the game. They felt their lack of familiarity with the ER activity and their teammates hindered smooth participation and game progression.

Our results corroborated with prior research and lent support to introducing the ER activity as an educational intervention *in lieu* of a live lecture (Abdul Rahim et al., 2022; Eukel et al., 2017; Veldkamp et al., 2020). Students positively perceived the ER activity and indicated that it was relevant and effective in enhancing their understanding of medicinal chemistry topics. According to them, the ER game was fun and interesting. The students perceived that they learned better in the game format than in a live lecture or a video lecture. It is reasonable to assume that the use of multiple themes in a gaming environment may appeal to Gen Z students. Though the puzzles were challenging, they seemed to enjoy the challenges during the gameplay. The overall results indicated the online ER activity promoted engagement, persistence on task and collaboration. These are critical conditions for deep learning (Eukel et al., 2017; Benlahcene, Kaur and Awang-Hashim, 2021). Nevertheless, some aspects of the game can be improved; for instance, a pre-game briefing will include a live briefing with written instructions, and a longer ice-breaking session for student teams with an increased time for the gameplay in the next iteration.

Based on the results, several recommendations can be made to enhance the effectiveness and enjoyment of the educational ER activity. Firstly, addressing the technical issues is crucial. Simplifying the platform use by either integrating the tools more seamlessly or reducing the number of platforms can minimise computer slowdowns and delays. Additionally, incorporating a more comprehensive pre-game briefing, possibly with written instructions alongside a live session, would ensure all participants are well-informed and prepared, especially those who might face disconnections. Extending the ice-breaking session would allow students to become more comfortable with their teammates and the ER environment, promoting better teamwork and engagement. Finally, increasing the overall gameplay time would not only accommodate students' need for familiarization but also allow them to delve deeper into the medicinal chemistry topics, thereby enhancing their learning experience. These improvements, centred around student needs and technical efficiency, can maximise the educational impact of the ER activity while maintaining its fun and interactive nature.

6. Limitations

While the study provides valuable insights, several limitations have to be acknowledged. The data, exclusively derived from a single cohort at one institution, could potentially limit the broader generalisability of the findings. In addition, the unfamiliarity of some students with the ER activity format resulted in comprehension difficulties, which may limit the applicability of the findings. For future research, expanding the study to include multiple institutions could diversify the data, potentially leading to more comprehensive results. In terms of future implementations, consideration could be given to the provision of initial training sessions on the usage of digital ERs. This could possibly lead to greater student engagement and enrich the overall learning experience. By addressing these areas, the potential for improved generalisability and relevance of the findings in the broader educational landscape could be increased.

With regards to the design-based research methodology adopted in this study, it is worth noting that the study only reported the first iteration of the ER design. There are several steps in the actual design-based research methodology that had to be improvised to suit the situation at that time, which was affected by the constraints imposed by the educational institution's timetable and resources. This resulted in a condensed design cycle that may not fully capture the iterative nature of design-based research, where multiple iterations of design, testing, and refinement are typically employed to optimize educational interventions. Future iterations of the ER design could benefit from a more extended timeline and access to greater resources, which allows for a more thorough refinement of the educational tool. Engaging in a collaborative design process with stakeholders such as educators, students, and technical staff could also enhance the relevance and usability of the ER activity.

7. Conclusion

This paper describes the design and implementation of a multi-themed, interactive ER activity in lieu of a synchronous Medicinal Chemistry lecture. In answering the research questions, the responses from the third-year pharmacy students have clearly indicated a positive perception of the multi-themed digital escape room (ER) activity, particularly in terms of engagement and learning experience. They have reported that the ER activity not only made the learning process more interactive and enjoyable but also significantly enhanced their understanding of medicinal chemistry topics. Furthermore, the study's findings suggest that the ER activity's innovative approach to teaching medicinal chemistry has been effective in making complex concepts more accessible and memorable, thereby underlining its usefulness as an educational tool in this field.

Recent studies on escape rooms in pharmacy education or chemistry were mainly based on only one theme (Abdul Rahim, 2023; Eukel et al., 2017). Existing literature reveals a dearth of research on the use of escape rooms to promote active learning in medicinal chemistry. Thus, to the best of our knowledge, this is the first digital escape room (DER) that focuses only on medicinal chemistry topics and employs multiple themes. For educators, the multi-themed DER activity, offers considerable flexibility and adaptability. The themes are versatile and can be effortlessly integrated and replicated in diverse educational contexts beyond Medicinal Chemistry.

Apart from the aspect of novelty, this study has also contributed to the pool of studies pertaining to ERs by highlighting the design structure and its corresponding tools. These could be a valuable point of reference in future research. The digital ER activity has demonstrated its value as a potential educational intervention to escape passive learning during didactic lectures, as supported by the findings of a systematic literature review on Digital Educational Escape Rooms (Makri et al., 2021). The ownership of learning the medicinal chemistry topics during the ER game challenges had shifted from the lecturer to Gen Z students. This provided invaluable opportunity for peer collaboration in the acquisition of 21st-century skills, aligning with the outcomes observed in the application of digital escape rooms in STEM education.

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On the Importance of Contextualizing an Educational Escape Room Activity

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Abstract: This paper describes the design and evaluation of "Enigma Bio", an educational escape room activity that aims to convey the abstract concept of biodiversity to children between 11 and 13 years of age, making them aware of the importance of climate change and its impact on biodiversity. The design of Enigma Bio is closely linked to the Biodiversity exhibition at the National Museum of Natural Sciences in Madrid, designed for a visit in groups of between 20 and 30 children, with an approximate duration of one hour, running on mobile devices and including augmented reality technology. The purpose of this research is to determine whether, in the case of educational escape room activities in museums with a limited time duration, it is more effective to have a pre-session introducing the topic. Our hypothesis is that without the context of the pre-explanation, the playful component of the game may be too powerful and may cause children not to pay enough attention to the message that the game intends to communicate, and even more so when dealing with a complex message such as the effect of climate change on biodiversity. To answer this research question, we follow an A/B testing experimental design involving two groups of children, one of which received an introductory talk on biodiversity and climate change before going to the museum and the other did not. The experimental design is completed with a pre-post evaluation of the children's environmental awareness by means of a previously validated questionnaire. The results of the experiment provide valuable insights into the effectiveness of the pre-session introduction in enhancing the learning outcomes of short educational escape room activities. Significant differences were observed between pre- and post-activity tests, indicating a moderate overall increase in awareness scores within both individual groups (A and B) as well as across the combined results. The findings suggest that the pre-session introduction indeed plays a role in enhancing students' awareness of the targeted message. These results represent a breakthrough in the e-learning practice that will be of value to other designers of educational escape rooms with a limited time duration.

Keywords: Educational escape room, Serious games, Games at museums, Augmented reality game

1. Introduction

Education is a major museum function, carried out by a dedicated staff and of concern to curators, exhibition designers, and other museum professionals. In large museums, the education staff, including part-time workers, docents, and occasional teachers, may represent up to 50 percent of all employees (Hein 2006). Museum educators engage in a broad range of activities, including tour programs, informal gallery learning programs, and family programs. Typically, educational activities involve some type of interaction with or around objects in the museum (Witcomb, 2006), which on many occasions may include some form of game (Beale, 2011). In the last few years, there have been a growing number of educational activities in museums using mobile devices to support interactive activities (Koutsabasis, 2017) and games (Paliokas and Sylaiou, 2016; Malegiannaki and Daradoumis, 2017).

The work presented here is motivated by several iterations in the design of the Enigma saga of games for museums developed by PadaOne Games as part of a growing number of initiatives incorporating augmented reality (AR) in exhibit-based informal science education settings (Goff, et al., 2018). The Enigma Bio game is conceived as a tool for educators guiding school groups on an approximately one-hour visit to the biodiversity exhibition at the National Museum of Natural Sciences in Madrid (MNCN, by its acronym in Spanish). The exhibition's content follows a thematic thread. It begins by introducing various forms of biodiversity, then links biodiversity to natural selection and adaptation to the environment, and finally addresses the threats to biodiversity, highlighting how human actions are impacting the climate and causing biodiversity loss.

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Climate change is a problem that the scientific community and the United Nations have been warning about through the yearly Climate Change Conferences held in the framework of the UNFCCC (United Nations Framework Convention on Climate Change) since 1992. Commercial video games such as "Alba: A Wildlife Adventure" by Ustwo Games (2020), "Beyond Blue" by E-Line Media (2021), and "Gibbon: Beyond the Trees" by Broken Rules (2024) are being used to raise awareness of the climate change problem among young people. The challenge for Enigma Bio is to achieve, in just one hour of play, a positive impact on the awareness of the participating children, taking advantage of the group experience in the physical space of the museum, the content of a specially designed exhibition, and the presence of an educator as a mediator of the experience.

Enigma games are treasure hunts designed specifically for museum settings, using image recognition and augmented reality (AR) on mobile devices to establish a link with the museum's content. Image recognition guides players through the museum's exhibits, while AR offers clues and supplementary content about these items. However, based on our previous experience in designing this type of treasure hunt game (Camps-Ortueta, et al., 2019), it is very difficult to combine the fun of the game with the control of the interaction of the group of children with the educator. The solution we have found for Enigma Bio, as described in this paper, is to turn the treasure hunt into a form of escape room where the educator takes a central role in the game by controlling the gates.

Enigma Bio arose in response to a need detected at the museum by educators. While new technologies increase children's engagement with proposed tasks, the available applications often do not align with the museum's specific needs. The idea of using the escape room format arose from the need for educators to have a video game that stops the action at certain points so that educators can give their explanations.

Research has shown the effectiveness of using games to raise awareness about the consequences of climate change and the actions we can take to mitigate its effects. (Flood, et al., 2018) discuss two types of games: short ones that serve as motivators, and longer games that allow players to delve deeper into the complex relationships among the factors involved in the problem. Enigma Bio falls within the short game category, with the goal of improving our comprehension of the implications of climate change on species extinction and biodiversity loss.

The main purpose of this research is to determine whether, in the case of educational escape room activities in museums with a limited time duration, it is more effective to have a pre-session introducing the topic. Our hypothesis is that without the context of the pre-explanation, the playful component of the game may be too powerful and cause children not to pay enough attention to the message that the game aims to convey, especially when dealing with a complex message such as the effect of climate change on biodiversity. To answer this research question, we follow an A/B testing experimental design involving two groups of children: one of whom received an introductory talk on biodiversity and climate change before going to the museum, and one who did not. We complete the experimental design with a pre-post evaluation of the children's environmental awareness using a previously validated questionnaire. Our findings may be useful for other designers of educational escape room activities.

The rest of the paper runs as follows. In Section 2 we introduce educational escape rooms and describe how Enigma Bio fits within that framework. Section 3 describes the design and the main game mechanics of Enigma Bio. Section 4 details the experiment we conducted to evaluate the effectiveness of the game and the impact of having a pre-session introducing the topic. Section 5 presents and discusses the findings from the experiment. Finally, Section 6 addresses conclusions and future work.

2. Literature Review

Escape rooms are live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to achieve a specific goal, usually escaping from the room, within a limited amount of time (Nicholson 2015; Wiemker, Elumir and Clare, 2015). From the original mission of escaping from a locked room, many variants have emerged that are nowadays also considered escape room games, including: solving mysterious murders, opening locked boxes, or unraveling mysteries in order to avoid the end of the world (Veldkamp, et al., 2020). The genre has grown and proliferated in all major cities in recent times. Numerous escape rooms have opened, offering visitors a wide variety of experiences. Additionally, over time, alternative games have appeared, some with digital support and others with physical support that also echo the great success.

Escape room games have also begun to gain traction in academia (Fotaris and Mastoras, 2019). Many escape rooms designed for the classroom have been simplified to a group tabletop activity involving a series of locked boxes (Schaffhauser, 2017), as it is not feasible or even legal to lock a subset of a class in a room and wait until they puzzle their way out. When properly designed, these types of games provide a motivating and immersive experience for students, although they may lose the feeling of complete immersion that escape room experiences provide (Clarke, et al., 2017).

Previous versions of the Enigma saga games for museums developed by PadaOne Games took the form of treasure hunts (Ihamäki, 2014). As such, they consisted of a sequence of searches, clues and quizzes that ran through a museum exhibit and were played at the participants' own pace. Although they worked as games and managed to attract the children's attention to the objects in the museum, they left the educator in the background as he had no role in the game and typically the children did not interact with him except at the beginning and end of the game.

According to Veldkamp, et al. (2020) Enigma saga games already included the main activity of educational escape rooms, namely, cognitive puzzles that make use of the players' thinking skills and logic. Nevertheless, by incorporating additional escape room game design ideas into Enigma Bio we have managed to meaningfully incorporate the educator into the game, without compromising the fun. These are the main design elements added:

- Divide the museum exhibition space into zones, each of which acts as a room, so that you need to solve all the puzzles in one zone in order to leave it and move on to the next.
- Introduce randomness in the order of the puzzles in a room, given that there is a group of people trying to solve the game independently (typically the game is played in pairs, where each pair shares a mobile device). When puzzles are always tackled sequentially in the same order, some players end up leading others, which can be addressed by introducing an element of randomness.
- Position the educator at the end of the zone, serving as the guardian of the room. This arrangement ensures that the objective in each room is to discover a question to pose to the educator. The winner from each zone will have the privilege of being the first to present the correct question to the educator. This setup ensures that all players will reach the educator as they progress through the zone, where they will convene. The educator will then offer an explanation related to their recent discoveries within the museum.

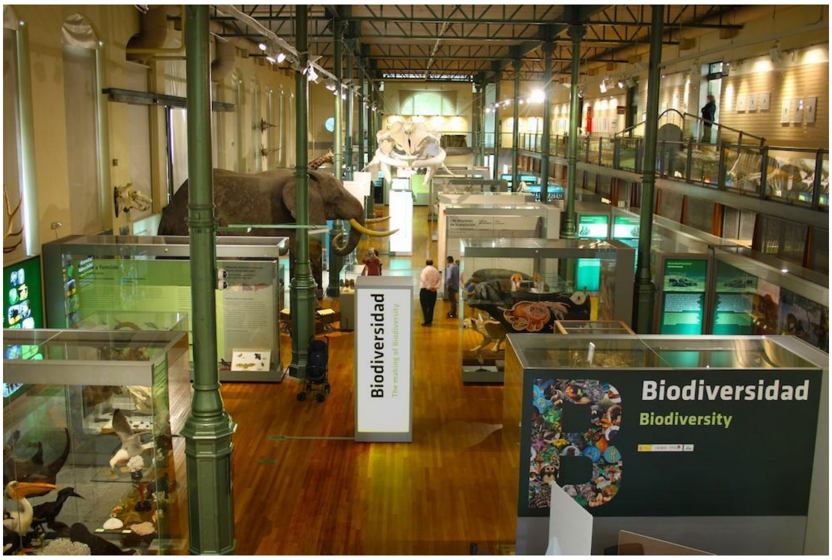
Next Section describes in detail the design of Enigma Bio.

3. Enigma Bio

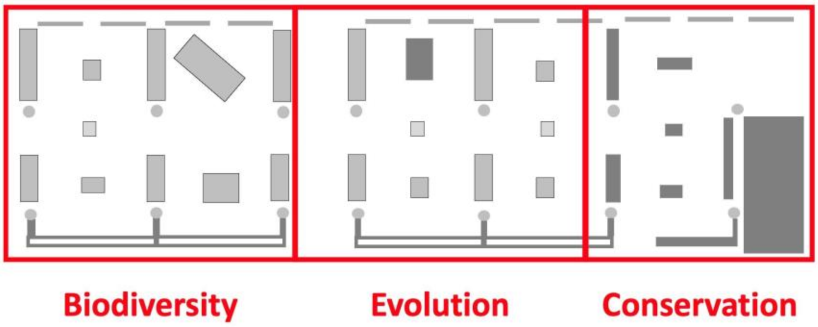
Enigma Bio is built around the biodiversity exhibition at MNCN. The concept of Biodiversity revolutionized the way we approach the study and conservation of nature by bringing together in a single concept the variety of species, their genetic variability, and their interrelationships with each other and with their environment. The exhibition, depicted in Figure 1a, attempts to answer these questions: What is Biodiversity? How has evolution shaped today's Biodiversity? How should Biodiversity be conserved? The exhibition is divided into three areas, as shown in Figure 1b: Biodiversity, Evolution and Conservation.

The first area of the exhibition explains what biodiversity is, how it is distributed in the different biomes of the world and how it manifests itself in the shapes, colors and relationships between the different organisms that make up ecosystems. Large collections of insects and mollusk shells then serve to explain the different levels at which we appreciate Biodiversity, from the gene to the ecosystem level. There is also a space to show how scientists try to order Biodiversity by classifying and naming living things.

The origin and the tree of life, whose branches link all living organisms evolutionarily, pave the way for the second area: "Biodiversity, the Fruit of Evolution." Here, the theory of evolution through natural and sexual selection is expounded upon, and its genetic basis is explained. Extinctions in the distant past, and more recent ones related to human activity, begin the area of "Conservation". This space not only reflects the direct causes of extinction and its victims, exhibiting extinct species such as the marsupial wolf, but also answers the questions of what, where and how to conserve.



(a) General view.



(b) Floor map.

Figure 1: Biodiversity exhibition at MNCN

As shown in Figure 1b, while the areas in the exhibitions are not physically separated, the display cases define spaces that can be perceived as connected, with “doors” enabling passage between zones. In Enigma Bio, each of these three “rooms” adhere to an open structure, allowing players to solve various puzzles simultaneously and without a specific order.

Enigma Bio’s core game mechanic centers on using a mobile device’s camera to search for artifacts, using image recognition technology. Players advance through a narrative adventure by following clues, answering questions, and engaging in different stages. Throughout these stages, participants encounter narrative elements, dialogues, artifact hunts, and blocks that regulate player advancement.

An artifact hunt prompts participants to use their device’s camera to locate an object indicated by a game clue. Successfully identifying the artifact completes the search. Usually, an augmented reality image or text will overlay the object, offering hints or additional information for the game. To encourage students to read the content of the explanatory panels in the exhibition, many of the object searches in Enigma Bio refer to details on those panels, as shown in Figure 2 where several children try to find a detail on the panel “the shapes of biodiversity”.

Figure 2: Interaction with the exhibition content

During a room stage, the participant has the freedom to interact with all the sub-sequences of artifact hunts and puzzles positioned within the room in any order they choose. To progress to the next stage from a room, the user must solve a final puzzle, which will only be possible to solve successfully after having completed the rest of the quests hidden in the room.

At the end of the room, the player will find a control stage in the game designed to prevent participants from progressing until they are given a keyword known only to the museum educator. This will allow to run the escape room in a synchronized manner for the group of participants, by allowing to wait until all participants have completed one room before granting passage to the next. And, more important, this will bring full attention of the children to the explanations of the museum educator, as shown in Figure 3.

Next, we describe the interface and more details about the main elements of gameplay in Enigma Bio. The complete game design, including the tutorial and three rooms associated with each of the three areas of the biodiversity exhibition, are described in (SPICE H2020 project, 2023).

Figure 3: Explanations of the educator

3.1 Enigma Bio Game Mechanics

The Narrative Screen (Figure 4) is a common resource in Enigma Bio. It consists of a character icon, character name, and a text box to communicate information and instructions to the player. Multiple narrative screens can be linked together, allowing for character changes, and creating interactive conversations.

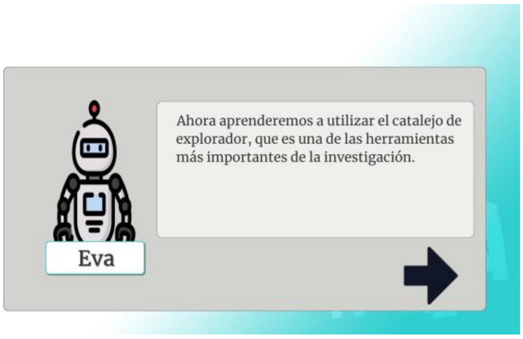


Figure 4: Character and Text screen

The Scan screen used in the game for artifact hunts can be seen in Figures 5a and 5b. By using the device's camera, it can track any image. Once the player finds the correct image, the overlay will change from "Searching" to "found" and the compass shown in the interface will change color to show that´s the correct image. Typically, in Enigma Bio a text or an image will be shown on top of a tracked image, as shown in Figure 5c where the image tracked is the puffer fish and the overlay indicates to search for the "shapes of biodiversity panel".

Since players will usually not be familiar with this mechanic, the main goal of the tutorial phase in Enigma Bio is help the player to learn how to use this tool, so that later she can use it in the escape room.

The Escape Room Screen, shown in Figure 6a serves as the central hub for every room in the game, featuring a total of 5 puzzle blocks. While four of these blocks are accessible at any time and in any order, the central block can only be accessed upon completing the other four.

(a) Scan Screen.

(b) Scan Screen in action.

(c) AR Overlay.

Figure 5: Artifact search

Once a block in the room is successfully completed, the player will receive a piece, as the one shown in Figure 6b, needed to solve the final puzzle in the room, and it will no longer be possible to re-enter that block. Completed items will undergo a color change to visually indicate their status as finished, accompanied by a new image display. As illustrated in Figure 6c, completed blocks exhibit puzzle pieces instead of the icons featured in Figure 6a. Notably, the central button is highlighted, signaling to the player that access to the final block has been unlocked.

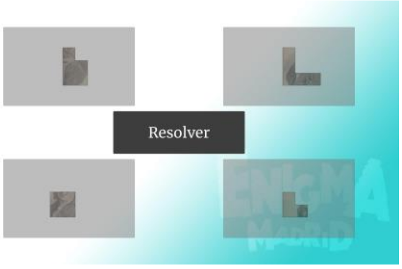
The final block in every room is a puzzle to be assembled with the pieces obtained in the room, and possibly, some others, as shown in 7. The solved puzzle will provide a clue for the next artifact to find, as, for example, in Figure 7, where there is a picture of Carl Linnaeus, which tells the player to find that same image for answering the next questions.

The game is interspersed with different types of questions that usually refer to the content of the exhibition panels. The idea is to alternate search phases with question phases, so that first we make sure that the player is in front of a certain panel and then we ask them a question whose answer is on that panel.

The basic type of question in Enigma Bio is a multiple-choice question as the one depicted in Figure 8a, that may have one or more correct answers. Upon providing a correct answer, a green checkmark will be displayed, or, in the case of an incorrect answer, the screen will exhibit a red cross (as shown in Figure 8b) and will also reveal the correct answer for reference. These are non-blocking questions since the player can proceed the game even with a wrong answer, but the number of right answers will be displayed at the end of the game and players will compete to obtain the highest score.

(a) Escape Room Screen.

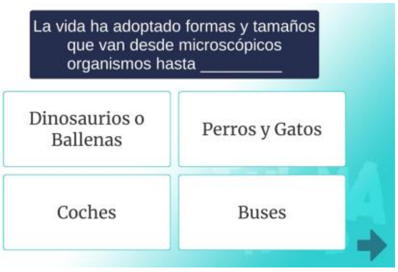
(b) Puzzle piece obtained.



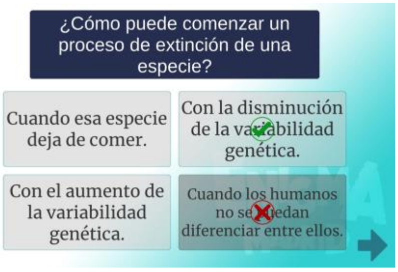
(c) Escape Room Completed.

Figure 6: Escape Room Screen

Figure 7: Puzzle Screen



(a) Question.



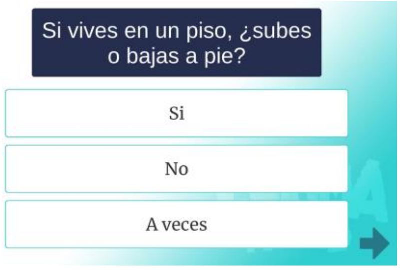
(b) Incorrect answer.

Figure 8: Multiple choice questions

There is also a question type that involves specifying a specific four-digit number. This format is particularly suitable for inquiries that require a numerical year as the answer. For instance, in Figure 9a, the question presented is: “In what year was the term ’Biodiversity’ first used?” with the correct response being: 1988. These are blocking questions because the game cannot proceed unless the correct answer is provided, thus forcing the player to find it.

Finally, there is also an open question type that entails a multiple-choice format without a designated correct answer. This type of question can serve various purposes, such as gathering insights about the player or functioning as a questionnaire at the conclusion of each level.

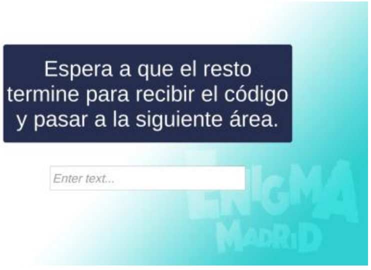
(a) Four-digit question.



(b) Open question.

Figure 9: Questions

Every room in Enigma Bio finishes with an "Introduce Room Code" stage as the one shown in Figure 10a. This screen prompts players to input a code for advancement. The code will be provided by the museum educator, once the correct question is posed to him. The last piece of information in every room is a question that must be posed to the educator. In order to promote competition, the educator will distinguish the first players to find the question, making them stand by him while providing the answer to the group, as shown in Figure 10b.



(a) Introduce room code.

(b) Museum Educator's explanation.

Figure 10: Room exit

4. Research Design and Method

In this experiment, first, we would like to assess whether playing Enigma Bio raises children's awareness of the threats posed by climate change. In addition, we would also like to answer the question of whether, in the case of short games in museums, it is more effective to have a pre-session introducing the topic. Our hypothesis is that without the context of the pre-explanation, the playful component of the game is too powerful, and the child does not pay enough attention to the message that the game intends to communicate. In addition, as this activity is aimed at primary school children, aged 11-13, our hypothesis was that the concept of biodiversity and its relation to climate change may be too complex in general for these children to grasp just from the museum activity.

In this experiment we had the participation of 57 children in 5th grade of primary school (ages between 11 and 13) who visited the National Museum of Natural Sciences on November 22, 2022. The children were randomly assigned to one of two groups, experimental group (29 children) and control group (28 children).

With a pre/post measures design, we attempt to address the hypothesis at hand: a pre-talk is necessary to develop greater awareness of threats to biodiversity related to climate change. The evaluation is carried out by means of a validated questionnaire on environmental awareness (van Valkengoed, Steg and Perlaviciute, 2021). The questionnaire, included in Appendix A consists of 5 factors that reflect the 5 most common perceptions regarding climate change: people's perceptions of the reality and causes of climate change, and the perceived valence, spatial distance, and temporal distance of the consequences of climate change.

The validated questionnaire provided by van Valkengoed, Steg and Perlaviciute (2021) consists of 7-point Likert scale responses to the questions posed where 1 is "strongly disagree" and 7 is "strongly agree". This type of response can be a problem for children of early age (Mellor and Moore, 2013). Therefore, we chose to simplify the questionnaire and offer students only 2 possible answers: "I agree" or "I disagree". With this modification the scores we will obtain are altered since the items only offer dichotomous scores (0 and 1) and each of the 5 factors offers a maximum score of 5 points if the subject is fully aware of the environmental impact of the factor in question.

The experimental setup involves two groups, both of which were given the validated questionnaire on environmental awareness at the beginning (pre). However, one group was also given a 30-minute lecture on Biodiversity and climate change before the museum activity, while the other was not. Both the initial questionnaire and the lecture took place at their school one week before the visit to the museum.

Both groups visited the museum and carried out the activity in the Biodiversity exhibition which consists of 50 minutes playing Enigma Bio with the active participation of an educator. Finally, one week after the visit to the museum, back at school both groups took again the environmental awareness questionnaire (post).

5. Findings

The results obtained demonstrate encouraging outcomes. Significant differences were observed between pre- and post-activity tests, with overall scores showing a moderate increase after performing the activity, both within each individual group (A/B) and across the combined results of the groups. This tendency can be seen visually in Figure 11, where the clustered distributions of the student scores before and after the activity are represented via a box plot.

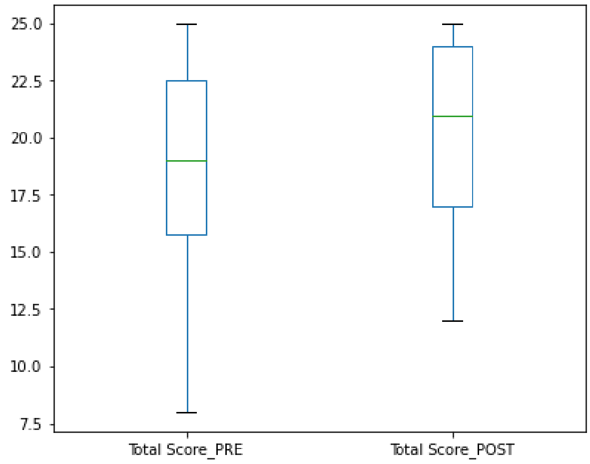


Figure 11: Box plot of the total score distribution (clustered samples)

After conducting the Wilcoxon signed-rank test for paired samples ($\alpha = 0.05$), we observed a clear and significant trend of score improvement among the students (refer to Table 1). The trend is evident and statistically significant in 3 out of the 5 factors assessed in the test, as well as in the overall total score. This test, however, only allows us to establish that there are significant differences at the individual level between test administrations, but by itself does not provide evidence of the direction of the changes.

Table 1: Clustered results of the validated environmental awareness test van Valkengoed, Steg and Perlaviciute (2021) (mean scores and significance of the Wilcoxon test for paired samples, N = 57)

	Reality	Causes	Conse-quences	Spatial Distance	Temporal Distance	Total Score
Pre	4.47	3.18	3.29	3.93	3.58	18.45
Post	4.62	3.83	3.94	3.83	3.63	19.85
p-value	0.0052	0.0020	0.0004	0.0028	0.0579	0.0013
Sig.	**	**	***	**	–	**

To address this concern, we can refer to the data on the proportion of students who improve their total test score, which amounts to 55% of the sample. When looking at individual factors, the proportion of improving students ranges between 16 and 33%, with a good number of participants whose scores in that factor remain unchanged between tests. In fact, if we analyze the number of factors in which students report better scores, we obtain an average of 1.16 factors ($\sigma = 1.02$, not accounting for the total). Consequently, we can confidently state that the activity significantly enhances the students' general awareness, regardless of whether they received the lecture or not, although this improvement is generally focused on a small subset of awareness factors per student.

The hypothesis aimed at validating the need to include a talk prior to the museum visit to reinforce awareness of the causes threatening biodiversity, particularly the role of climate change as a threat, was moderately supported by this experiment.

After the initial administration of the questionnaire, a Mann Whitney U test was conducted to assess whether the factor-to-factor and total scores' distributions of control and experimental groups before the activity were similar. The results indicated no significant evidence to reject the null hypothesis of similarity of populations in all comparisons (for the total score, p-value = 0.44). In other words, both randomly chosen groups exhibited similar behavior before the activity, a crucial factor in avoiding bias in the experiment.

As shown in Tables 2 and 3, the students assigned to the experimental group exhibit marked and positively trending significant differences in their individual behavior concerning 2 out of 5 considered factors, as well as in the overall score. On the other hand, the control group does not perceive statistically significant differences in the total score of the questionnaire, although it does show moderately significant positive changes in 2 out of 5 factors. Both groups seem to display a subtle negative trend in the spatial distance factor, although the difference in the mean is not particularly high in either case.

Table 2: Control Group (no presentation before)

	Reality	Causes	Conse-quences	Spatial Distance	Temporal Distance	Total Score
Pre	4.50	3.36	3.46	3.86	3.86	19.04
Post	4.74	3.59	4.11	3.78	3.89	20.11
p-value	0.0103	0.1797	0.0177	0.0378	0.1638	0.0845
Sig.	*	–	*	*	–	–

Table 3: Experimental Group (with presentation before)

	Reality	Causes	Conse-quences	Spatial Distance	Temporal Distance	Total Score
Pre	4.44	3.00	3.11	4.00	3.30	17.85
Post	4.48	4.08	3.76	3.88	3.36	19.56
p-value	0.1342	0.0050	0.0086	0.0369	0.0964	0.0059
Sig.	–	**	**	*	–	**

In summary of the results collected from the group analysis, the following points of interest can be established:

- The experimental group shows a statistically significant and positive individual trend in their overall awareness level, while in the control group, there is not enough evidence to confidently establish a similar result. However, in the latter group, the p-value falls below 0.1, and the pre- and post-experiment means are separated by about one point, indicating that the differences in trends between groups are not as pronounced as initially perceived.
- The experimental group appears to have a markedly positive effect on the students' awareness concerning the factors of causes and consequences. The improvement in consequences also extends to the control group, which shows significant improvement in this aspect as well.
- The control group exhibits a statistically significant and positive difference in the reality factor, although the group's mean remains close to the original.
- Both groups display a moderate negative trend in the spatial distance factor, although the differences in the means are not particularly pronounced.

5.1 Discussion

The main aim of an educational game is to use the playful experience as a vehicle for introducing significant learning (Djaouti, et al., 2011). If the design of games is already an activity that requires large doses of creativity and knowledge (Fullerton, 2008), the design of educational games also requires finding a balance between learning and fun that makes it especially demanding (Shute, et al., 2020), and even more so when dealing with a complex message such as the effect of climate change on biodiversity. Nonetheless, others have demonstrated the effectiveness of using games as a means to raise awareness and educate on biodiversity-related issues such as climate change (Reckien and Eisenack, 2013; Flood, et al., 2018) or sustainability (Fabricatore and Lopez, 2012; Nordby, et al., 2016; Mercer, et al., 2017). Enigma Bio faces additional challenges targeting primary school children aged 11-13, who may find it difficult to understand certain abstract concepts, and even more so if the experience is restricted to the short duration of a school visit to a museum (Camps-Ortueta, et al., 2023). The solution we propose to add an introductory session prior to the game in the museum is in line with Markmlund and Taylor (2016), who states that is not only the game but also the context that matters when we talk about educational games.

The results of the experiment provide valuable insights into the effectiveness of the pre-session introduction in enhancing the learning outcomes of short educational games. Our hypothesis, which posited that without the context of a pre-explanation, the playful element of the game might overshadow the intended message, was moderately supported by the findings. Significant differences were observed between pre- and post-activity tests, indicating a moderate overall increase in awareness scores within both individual groups (A and B) as well as across the combined results. This trend can be visually observed in Figure 11, depicting the distributions of student scores before and after the activity.

Nonetheless, there are differences in the factors that van Valkengoed, Steg and Perlaviciute (2021) refers to as "climate change perceptions": upon closer examination, it is evident that the activity contributed to a statistically significant and positive individual trend in the overall awareness level of the experimental group. However, the control group did not exhibit strong enough evidence to confidently establish a similar result. Although the control group displayed a lower p-value and a noticeable separation between pre- and post-experiment means, differences in trends between the two groups were not as pronounced as initially anticipated.

The findings suggest that the pre-session introduction indeed played a role in enhancing the students' awareness of the targeted message, though further experiments would be required to reinforce this claim on a more general basis. The experimental group displayed marked improvements in understanding the factors related to causes and consequences of biodiversity loss, with the control group experiencing subtler enhancements in these aspects. This implies that the introductory context helped students better comprehend the nuanced relationships presented in the game that were related to these factors.

On another note, the results regarding spatial and temporal distance perceptions yielded unexpected findings. Contrary to our anticipation, students either slightly regressed in these aspects or exhibited insignificant changes post experiment. This surprising outcome prompts a closer look at the complexity of these concepts for young learners.

The intricate nature of spatial and temporal dimensions, especially when connected with the abstract concept of climate change, might pose challenges for primary school children's cognitive understanding. These complex interrelationships may demand a more advanced cognitive development level to be fully grasped.

Considering that spatial and temporal concepts are often challenging even for individuals of various ages, the difficulty could be magnified for children in the primary school age group. The gradual and subtle nature of climate change effects over time and space could require tailored teaching approaches that bridge these abstract notions with the students' real-world experiences.

6. Conclusions and Future Work

In this study, we have introduced Enigma Bio as an enhanced version of the enigma saga's treasure hunt games, infused with escape room elements to enrich the puzzle-solving experience. By incorporating educators into the gameplay mechanics, we have transformed the game into a valuable tool for engaging students.

Our initial findings shed light on the game's effectiveness, even within its brief duration, a result that could be attributed to the immersive museum setting. Interestingly, initial outcomes also suggest that prior exposure to relevant concepts, such as biodiversity, could amplify the game's impact. Notably, the experiment highlighted the positive influence of a pre-session introduction on the efficacy of short educational games in helping primary school children understand complex concepts. While both groups showed increased awareness, the experimental group, armed with contextual introductions, demonstrated more substantial improvements, particularly in comprehending the intricate relationship between biodiversity and climate change, especially regarding climate change's effects and consequences on biodiversity. These findings underscore the crucial role of well-designed instructional strategies in facilitating young learners' grasp of intricate subjects and fostering a stronger connection to real-world challenges.

Looking ahead, our research will expand into more comprehensive experiments to provide conclusive insights into the effectiveness of our approach. Further exploration into optimizing learning outcomes for young students will involve refining the timing, content, and delivery of pre-session introductions. Additionally, considering the unexpected trends in spatial and temporal distance perceptions, we propose investigating the cognitive development trajectory of young learners in understanding complex environmental concepts. Innovative pedagogical strategies and gamifications aimed at making these abstract notions more relatable could prove vital in nurturing a more accurate and comprehensive understanding of climate change and its significance in the lives of primary school children.

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Appendix: The Questionnaire

Reality

1.	I believe that climate change is real.
2.	Climate change is NOT occurring.
3.	The world's climate is changing.
4.	I do NOT believe that climate change is real.
5.	Climate change is happening.

Causes

1.	Human activities are a major cause of climate change.
2.	Climate change is mainly due to natural causes.
3.	Climate change is mostly caused by human activity.
4.	The main causes of climate change are human activities.
5.	Climate change is caused entirely by natural processes.

Valence of consequences

1.	Overall, climate change will bring more negative than positive consequences to the world.
2.	Climate change will mostly have positive consequences.
3.	Climate change will bring about serious negative consequences.
4.	The consequences of climate change will be very serious.
5.	There will be mostly positive consequences of climate change.

Spatial distance

1.	My local area will be influenced by climate change.
2.	Climate change only influences locations far away from me.

3.	The region where I live will experience the consequences of climate change.
4.	The consequences of climate change will only take place in distant locations.
5.	Climate change will also influence the place where I live.

Temporal distance

1.	The consequences of climate change are visible now.
2.	It will be a long time before the consequences of climate change are felt.
3.	Only future generations will experience the consequences of climate change.
4.	The consequences of climate change will only be experienced in the far future.
5.	The effects of climate change will be felt very soon.

Unlocking Learning: The Impact of an Educational Escape Room on Energy Transition

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Abstract: Since the first escape room opened in 2007, the industry has grown to attract people from all over the world and is expected to continue to grow. This trend of rising social and recreational interest has, in turn, being introduced in the education sector in many countries. The use of escape rooms for educational purposes has become increasingly popular across different levels of education, including higher education institutions. This innovative and ludic approach involves students in their learning environment, encourages the use of numerous soft skills (creativity, problem solving, teamwork, etc.), and provides opportunity to escape the 'routine' of traditional and less student-centered learning methods. Although Educational Escape Rooms (EER) are becoming more prevalent in formal education, initiatives related to the topic of energy transition are scarce. As a result, there is limited information on the impact of these strategies to promote youth motivation and learning towards the energy transition. Exploring this issue is particularly relevant as young people have the potential to play an active and important role in achieving a sustainable future. This case study employs a quasi-experimental pretest-posttest design with mixed data. The sample consist of 32 students playing an EER, designed by higher education students, on energy transition. The study aims to assess the quality of the resource design and its impact on students' knowledge, motivation to learn, soft skills utilization, and engagement. The study results show a noteworthy improvement in self-perceived knowledge regarding the energy transition after playing the EER. This increase is associated with new knowledge gained by the players about energy consumption, production and transformation. The results indicate that the EER is ineffective in increasing or decreasing motivation to learn among players. Engagement is perceived as positive with respect to the experience of playing the EER. However, there is no correlation between motivation to learn and engagement. The study also suggests that the EER has the potential to improve various soft skills, especially teamwork, communication, and problem-solving. Finally, the EER was generally praised by the players for its engagement, on both quantitative and qualitative data in the study. On the other hand, the thematic analysis revealed some design issues that may have affected the players' experience and learning outcomes. These included excessive difficulty in some puzzles, lack of guidance, and insufficient time to complete. These issues need to be addressed in order to improve the overall impact of the EER, despite players' generally positive perceptions of it. In relation to the four puzzles that compose the EER (which relate to energy consumption, production, storage and transformation), they were generally positively rated by the participants, with the energy consumption puzzle being the highest rated for its practical application.

Keywords: Educational escape rooms, Game-based learning, Energy transition, Higher education institutions, Learning environment, Climate change

1. Introduction

The industry of escape rooms, defined as "a live-action team-based game where players discover clues, solve puzzles, ad solve tasks in one or more rooms to accomplish a specific goal in a limited amount of time" (Nicholson, 2008), has expanded to reach individuals from diverse geographical locations since the inaugural escape room opened its doors in 2007. Recent data indicates that there are currently 50.000 escape rooms worldwide. While this may seem like considerable number, the industry is still growing and is expected to expand further. Many individuals are not yet aware of escape rooms, and new players will enter the market when they discover the industry (Megens, 2022). As the escape room market grows, the competition intensifies. The initial generation of escape rooms concentrated on challenging logic puzzles. However, contemporary escape rooms have evolved into fully immersive environments with high-quality props and effects (Wiemker, Elumir and Adam, 2015). Escape room businesses are developing innovative concepts and themes that attract large audiences, and escape room owners are incorporating virtual reality, interactive technology, and even outdoor games (Megens, 2022).

The application of recreational escape rooms for educational purposes has become increasingly popular as a means of engaging young people in their learning environment. This approach is designed to encourage the development of both hard skills and soft skills, including critical thinking, collaboration, and communication

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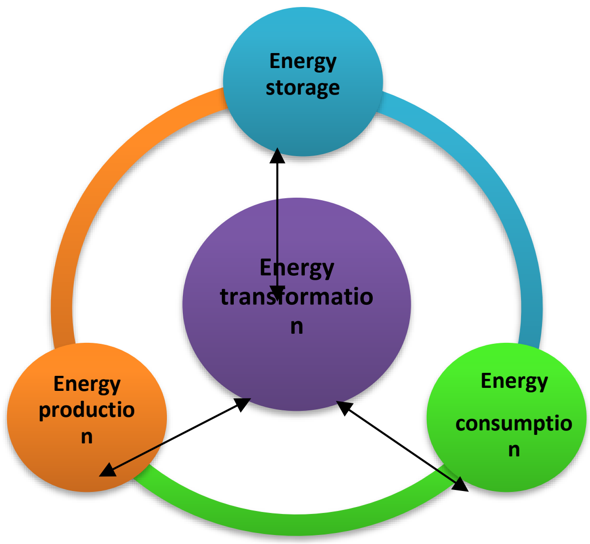
(Ouariachi and van Dam, 2022). In higher education institutions, Educational Escape Rooms (EER) have gained popularity as means of motivating learning in innovative ways. This is partly due to the response to an environment of increasing "performativity" and "instrumentalism" in education (Ball, 2012; Taraldsen *et al.*, 2020), but also as a way to convey complex issues to young people, such as climate change or the energy transition.

However, when discussing the topic of energy transition, initiatives are notably absent, and only a select few follow a bottom-up approach and are designed by students for other students. Consequently, there is limited knowledge about the effects of these strategies on young people's engagement in energy transition. This is particularly pertinent given the significant potential of young people to play an active role in the energy transition. It is therefore important to ascertain whether EERs can inspire youth to learn more about and work collaboratively.

In this context, the project entitled "*Beat the Clock, Turn the Lock! Educational escape rooms to accelerate the energy transition*" -supported by Comenius Teaching Fellowship / Netherlands Initiative for Education Research (NRO) and the Centre of Expertise Energy (Hanze University of Applied Sciences)- was created at Hanze University of Applied Sciences (Groningen, The Netherlands). The final outcome of this project was the creation of an EER on energy transition designed by students for students. The Center of Expertise Energy at Hanze University is dedicated to exploring novel approaches to engaging the student community into energy transition. This project was integrated into the subject "*Communication & Behavior*" within the Master's program *Energy for Society* during the second block. The students of this Mater's program were tasked with designing the EER, with the support of a group of coaches. In the initial phase of the subject, 20 students received instruction in the theoretical principles of behavioral change, communication strategies, and persuasion. In the second part of the subject, the class was divided into small teams of four students to work on the development of the escape room. Over the course of several weeks, these teams engaged in a process of design, creation and testing. Each small team was responsible for developing a different mission (story and puzzle) centered on a specific area within the energy transition (and a specific learning outcome for each topic), including consumption, production, storage and transformation (Fig. 1). Concurrently, they applied the knowledge acquired in the theoretical classes and practiced essential skills, such as creativity, problem-solving, collaboration, and critical thinking.



Energy Consumption	How to decrease your energy bill?	Isolation, energy reduction
Energy Production	How to provide your own energy?	Solar panels, wind energy
Energy Storage	How to store energy for later use?	Batteries, water storage
Energy Transformation	How to create a fully functioning system?	Smart homes, hydrogen

Figure 1: Topics covered

In the course of developing the game, the students engaged in coaching sessions and were guided by a team of experts in game design, energy, psychology and communication. Finally, the different missions were integrated into a final prototype. The following puzzles were designed by students for each of the categories and were part of the final prototype:

1. Energy consumption puzzle: different appliances (heaters, lamps, etc.) are required. The objective is to identify the three most efficient appliances, as determined by a watt meter. Each appliance is assigned a number, and when they are sorted, they generate part of a code that must be entered to continue the game. The last number of this code is hidden in a map on the wall. The final number can be identified through the use of an insulating material with a hole in it. Upon opening the box containing the code, the player will receive a light bulb, which is necessary for the subsequent puzzle.
2. Energy production puzzle: the players must solve a riddle that involves the use of a morse code. The initial stage utilises a small solar panel, which, upon activation, illuminates and deactivates a light bulb, thereby generating the first part of the morse code. The second part of the code is obtained through a small riddle about the relationship between wind energy and solar energy, presented on a poster. By solving the code, the participants obtain a dead battery, which they will require in puzzle 3 and 4.
3. Energy storage puzzle: Players must identify a method for recharging the battery in order to utilize the UV light. To accomplish this objective, players must respond correctly to inquiries concerning the geography of various continents on Earth. This is necessary to utilize the charging station.
4. Energy transformation puzzle: utilizing the battery charging station, players can obtain a charged battery that can be employed to power an electrolyser, thereby enabling the production of hydrogen. Subsequently, the hydrogen can be transported to the "engine" of the carriage, which represents the ultimate objective of the escape room narrative. Once the connection has been established, a beep will be emitted. This is the signal that the escape room has been completed.

The educational escape room, situated within an old container, employs a sequential puzzle path structure. Its narrative is inspired by that of the science fiction action film Snowpiercer (Fig. 2 and 3).

Figure 2: Playing session

The final prototype was first tested by the entire design team, followed by a group of 8 students who represented a sample of their primary target audience at a live event. This allowed them to assess the prototype and analyze the outcomes and impact of their own intervention before launching it to the whole student community. A debriefing session between the coaches and students was held at the end to reflect on the experience.

Following the initial piloting of the EER and the subsequent adjustment of certain aspects of its design based on the subsequent evaluation, the present research was conducted with a sample of 32 students from the International Communication Master program. A volunteer student from Hanze University facilitated the game sessions. One week prior to their game session, the students completed an online ad hoc pre-test questionnaire. This questionnaire explored their previous experience with escape rooms, as well as their knowledge and motivation to learn about energy transition. One week later, students played the EER for a maximum of 60 minutes(the time limit for completion) on a voluntary basis and outside of their academic timetable, and completed the post-test questionnaire with mixed questions about energy transition and the quality of the escape room itself.

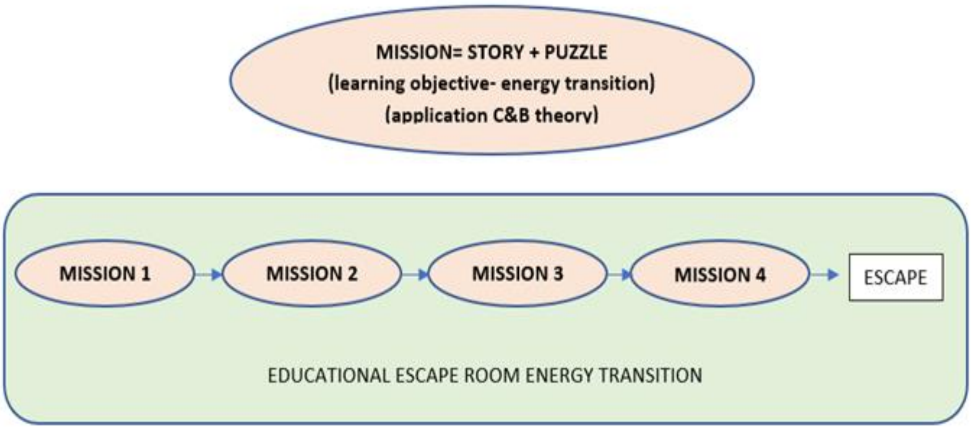


Figure 3: Escape room set-up

The aim of this research is to assess the quality of the EER design and its impact on students' knowledge and motivation to learn about energy transition, as well as their use of soft skills and engagement. The study intends to explore the pedagogical potential of EER as an innovative methodology, especially in the case of energy and climate change education, an under-explored area. To achieve this, a mixed pretest-posttest questionnaire methodology is applied to address the following research questions:

Main research question: to what extent playing an Educational Escape Room (EER) on energy transition can improve university students' knowledge, motivation to learn, use of soft skills, and engagement?

Sub-question 1: Does playing an EER on energy transitions significantly increase students' knowledge about energy transitions? What are the main new learnings expressed by players about energy transition?

Sub-question 2: Does participating in an energy transition EER significantly enhance motivation to learn about energy transition?

Sub-question 3: What are the soft skills that students report using during the EER?

Sub-question 4: What are the most representative positive and negative design aspects that players express about the EER?

2. Literature Review

Escape rooms represent a relatively recent form of interactive entertainment based on a specific theme and narrative. In these experiences, small groups of players work together to complete a series of puzzles or challenges to win in a limited amount of time (Whitton 2018; Wiemker, Elumir, and Clare 2015). The application of recreational escape rooms for educational purposes has become increasingly popular as a means of engaging young people in their learning environment. This approach is thought to encourage the development of both hard skills and soft skills, including critical thinking, collaboration and communication (Ouariachi and van Dam, 2022).

The question is whether the use of these interactive tools can foster engagement in learning. This question becomes particularly pertinent when learning about complex topics such as climate change or the energy transition. The inherent complexity of these topics gives rise to a number of doubts and questions among educators, who frequently recognize that their knowledge is deficient and fragmented, and that they hold a number of misconceptions (Lombardi and Sinatra 2013; Ratinen 2016). In their review of the literature on effective teaching strategies for climate change in formal settings, Monroe *et al.* (2019) identify two main approaches: focusing on personally relevant and meaningful information, and using interactive and engaging teaching methods. In relation to the latest approach, interventions that were highlighted included an experiential, inquiry-based, or constructivist approach, such as the case of EERs.

The literature indicates that Educational Escape Rooms (EER) exhibit several positive characteristics. These include: a) experiential and immersive: while the first generation of escape rooms were centered around difficult logic puzzles, the current generation has become fully immersive environments with high-quality props and effects (Wiemker, Elumir, and Clare, 2015); b) problem solving: EER are developed to engage the mind and solve problems, which makes them an excellent addition to the learning environment of the classroom (Nicholson 2018). Additionally, they can be constructed around any discipline, which allows them to align with curriculum (Clarke *et al.* 2017); c) critical thinking: EER encourage players to think creative, unconventional, and innovative ways, employing diverse approaches to knowledge (Whitton 2018; Wiemker, Elumir, and Clare 2015); d) collaboration: EER are based on teamwork, and puzzles are designed in such a way that every player can contribute in a meaningful way (Wiemker, Elumir, and Clare, 2015). This approach sets the foundations for active learning and social constructivism (Nicholson 2018); and e) sense of urgency: setting time limits can create a sense of urgency, which challenges students to engage with the content and complete the puzzles in a way that a traditional activity structure may not (Clarke *et al.* 2017; Nicholson 2018).

In the context of escape rooms implemented in classrooms, the existing literature identifies two principal types of case studies. The first category encompasses escape rooms that have been specifically designed by educators for students. A significant proportion of these games are related to medical education, as evidenced by the example of the EER developed at University of Ottawa. This escape room, themed around vascular surgery, was designed by faculty members with the objective of enhancing the motivation, satisfaction and engagement levels of medical students (Kinio *et al.* 2019). The second category comprises escape rooms designed by students for students, which follow a pedagogical approach based on the concept of "learning by designing". Our project is in fact integrated into the second category, as it was previously introduced. The learning by design approach emerges from constructivism and emphasizes that students learn in the context of attempting to overcome design challenges. During the design, testing, explaining, learning, and redesign cycle, as students work iteratively to refine their design, they also enhance their understanding of concepts and gain experience in a range of skills. Throughout, the design challenge serves as a unifying element, connecting inquiry, investigation, drawing conclusions, and application.

In their examination of EER experiences in the field of climate change, Ouariachi and Elving (2020) identify 17 initiatives that were grouped into four categories. The first two categories encompass EERs that have been implemented in classrooms. These include initiatives created by educators or sustainability offices at universities for students, as well as those initiated by students themselves. The third type of initiative is a one-day event escape room aimed at the general public, which frequently focuses on raising awareness about city plans. The fourth type is a product that can be purchased online, either from private companies or individuals, targeting the general public or other educators. This allows them to avoid the necessity of designing an escape room themselves and instead implement the puzzles and narratives directly in their classrooms.

As an illustrative example, "Escape Climate Change" (Germany) is sold on its website as an "interactive game for schools that engages with the subject of climate protection in a fun and exciting way". In this instance, the format is a mobile game designed for secondary school students aged 16 and above. The objective is for students to work collaboratively to decipher a final secret code in order to gain access to the contents of a case. To achieve this, participants must solve a series of puzzles and tasks, relying on a combination of instinct, teamwork, logic and web research, and using an app developed exclusively for the game. The game can be played without the need for additional preparation or materials.

Another initiative, "Climate Change Escape Room Game", offers teachers a game to educate children about deforestation and climate change, and the effects of global warming, especially for the beginning of a topic to introduce information or at the end to recap. The game's objective is to facilitate the acquisition of factual information and its subsequent application in the resolution of puzzles. These puzzles may take the form of answering clues or decoding ciphers, with the player tries to "help an alien". The game's duration is approximately 45 minutes. Another noteworthy example of a climate change-related escape room is "Escaping Global Warming", developed by AppRuption (AppRuption, n.d.), a digital EER that guides players on a journey to learn about the causes and impacts of climate change. The escape room is designed to be interactive and engaging, with puzzles and challenges that facilitate an understanding of the science behind climate change and the actions that individuals can take to reduce their own carbon footprint.

In conclusion, climate change-related escape rooms can be a highly effective educational tool, as they facilitate raising awareness about the urgent need to address climate change and encouraging individuals to take actions to reduce their own carbon footprint. However, when discussing the topic of energy transition, initiatives are notably lacking. The initiatives founded are primarily designed for middle school and high school students, with the objective of educating them on various aspects of energy, including the classification of the energy sources, the distinction between renewable and non-renewable energy sources, and the implications of energy consumption. One illustrative example is "Connected to the Future: The Energy Transition", an interactive event designed to raise public awareness about the impact of climate change. It outlines the challenges of energy transition, highlights the sustainability goals of the 2030 Agenda, and emphasizes the important role that individuals can play in shaping the future. Another example is the "Renewable and non-renewable energy escape room," which is designed for middle and high school students. It simulates a power outage scenario where students must use their knowledge of energy sources to restore power and escape the room. The objective of this activity is to enhance students' comprehension of renewable and non-renewable energy sources (Kesler Science, n.d.). In conclusion, the majority of these energy transition-related escape rooms are still in their early stages and are presented in the form of traditional puzzles, which test the knowledge of students.

3. Theoretical Framework

The primarily theoretical foundation of this paper is game-based learning (GBL), which entails incorporating game characteristics and game principles into the learning activities themselves (Gee, 2003). With regard to the use of EERs as a method, the student's learning cycle exhibits certain characteristics during the activity. In the initial phase, participants are presented with a novel situation, which prompts them to investigate the available resources for the activity. Subsequently, they will discover some clues and commence to understand the progression of the game, as well as the steps needed to solve the puzzles. Students will need to remember some content and apply it to the game through trial and error until they identify the solution. During this process, collaboration, creativity, communication and critical thinking will occur between the participants as they attempt to solve the challenges. As stated by Pass, Homer and Kinzer (2015), there are a number of arguments in favor of game-based learning. While some of these arguments have little empirical support, others are firmly grounded in existing research. These are motivation, player engagement, adaptability and graceful failure. In this context, there is a group of scholars that has proposed that game-based learning involves processes that differ significantly from those observed in other forms of learning, to the extent that they should be described as a unique model or theory of learning (Gee, 2003; Prensky, 2003).

The constructivist philosophy of learning, which is generally attributed to Piaget (Wadsworth, 1996), is at the core of game-based learning. The constructivist approach is centrally based on the notion that learners construct their knowledge, building upon their existing knowledge base. Empirical evidence indicates that students learn most effectively through constructivist approaches: concrete experience provides information that serves as a basis for reflection, which in turn facilitates the assimilation of abstract concepts. In the context of climate change education, Taber and Taylor (2009) research founds that students demonstrated the greatest learning outcomes when engaged in hands-on activities aligned with constructivist approaches. In their study on effective climate change teaching methods, the researchers found a direct relationship between increased understanding of climate change and concern about the issue. Nevertheless, constructivist teaching is not a magic bullet, and some locally-based activities that teachers prepare may not necessarily facilitate connections to the global scale (e.g. consumption), thereby questioning its transformative impact.

In the context of the project, the team of coaches used the escapED Framework (Clarke *et al.* 2017), which is based on constructivism, to provide a foundation and structure to the game-based learning experience. This framework was developed and implemented successfully at Coventry University to explore, experiment and exploit game design in fostering creative problem solving and cross-disciplinary design collaboration. It was found beneficial to conceptualize the interactive experience in the context of in higher education settings. As the authors of the framework state, this approach "challenges the current inclination towards adopting digital games and technologies as the leading method of delivering and exploring GBL", defending a more holistic method toward inclusive, learning-oriented game design and development (Clarke *et al.*, 2017). This framework comprises six principal areas that should be considered when developing an EER: participants, objectives, theme, puzzles, equipment, and evaluation. The following table (Table 1) provides a summary of the framework's application to the project.

Table 1: Framework application

Areas	Elements
Target	1) Designers: master students 2) Players: other Hanze students
Objectives	1) Reinforce knowledge (energy transition, content of the course) 2) Increase motivation in learning 3) Practice skills
Theme	Students choose general storyline, setting, genre Energy transition divided in 4 topics (each team, one topic): Energy consumption ; Energy production; Energy storage; Energy transformation
Puzzle	Lineal structure Each puzzle: 10-15 min. related to a learning objective within energy topic 3 rounds of hints; Difficulty: low-moderate; Time: 60min
Equipment	Container rent; Material: 100 euros per team; HanzeMakerSpace
Evaluation	Pre-test / Post-test

4. Methodology

The conducted research is a case study with a quasi-experimental pretest-posttest treatment. The intervention involved playing an EER on energy transition, which was designed by students of the master program *Energy for Society* from Hanze University of Applied Sciences, Groningen. To analyze the effect of playing this EER on learning, two questionnaires were used. The questionnaires contained mixed data and were developed ad hoc within the framework of the research project *"Beat the Clock, Turn the Lock! Educational escape rooms to accelerate the energy transition"*. The decision to develop the questionnaires in an ad hoc manner can be attributed to the observation that, following a review of several scales proposed in other studies (e.g. Cai, 2022; Clauson *et al.*, 2019; Eukel *et al.*, 2020), none of the aforementioned scales were deemed to be sufficiently aligned with the multivariate analysis sought in the present study, which aimed to collect data on prior experiences, knowledge, motivation to learn, perceived use of soft skills, and engagement. Additionally, a proprietary questionnaire provides the flexibility and ability to delve into specific aspects of EER design (an under-explored area), while the inclusion of open-ended questions encourages the exploration of new ideas and areas of research within this emerging field. In both questionnaires, students were asked to answer the following questions on a scale of 1 to 5: ''How knowledgeable do you feel about the energy transition?'' and ''How motivated are you to learn more about these issues?". Specifically, in the post-test, two additional quantitative questions were added: " To what extent do you think you have used the following skills (teamwork, problem-solving, critical thinking, creativity, logic, time management, communication, concentration, empathy)?" and "How much do you think this was an engaging learning experience?", as well as three qualitative/open-ended questions: "Please indicate anything new you have learned from this experience in relation to the energy transition", "The Escape Room is designed as an educational tool. With this in mind, what do you think worked well?" and "What do you think didn't work so well?".

The questionnaires and EER prototype underwent two previous pilots to assess their quality, reliability, validity, and internal consistency. The first pilot involved the EER designers themselves (n=20), while the second pilot was conducted by a voluntary group of 8 students from the *International Communication* Master program, which is the target audience. Additionally, validity decisions were made through a consensus assessment by three expert professors.

The final sample for the study were 32 students from the *Master of International Communication* at Hanze University of Applied Sciences with different academic and cultural backgrounds. More than half identified as female (n=24) and 8 as male, with ages ranging from 22 to 34 years. These students volunteered to play the EER during Block 3, outside of class time. For the game sessions, a Hanze student volunteered as a game facilitator. He was trained beforehand by the coaches and received a document with guidelines for the introduction, narrative, puzzle hints, game reset and debriefing. The pretest was emailed to the participants when they registered for the game (one week before the game) and the game facilitator shared the post-test with the students immediately after the game.

The statistical analysis of quantitative data was conducted using the latest version of SPSS software. Descriptive analysis, paired samples t-test analysis for intra-group differences due to the intervention, and inferential and correlational analysis for intra-item trends were employed. For qualitative analysis, NVivo software was used. A Thematic Analysis methodology, specifically inductive, was implemented to test the themes and sub-themes that emerged from the data. This study follows the ethical principles in research as described by the Research Ethics Committee, the Declaration of Helsinki, and the Ethical Guidelines of Hanze University of Applied Sciences.

5. Findings

5.1 Prior Experience and Rate About Escape Room

First, students were asked if they had ever played an escape room, either for educational or recreational purposes, and if so, to rate their experience on a scale of 1 (poor) to 5 (very good). In response to these questions, 68.4% of the total sample (n=26) indicated that they had previously played an escape room, and again rated the experience with an average score of 3.08 (SD = 1.23) out of a maximum of 5, placing it in a quasi-neutral mean.

5.2 Knowledge About Energy Transition

To assess the potential effect of the EER on the cognitive domain, participants were asked to rate their knowledge of the energy transition on a scale of 1 (not at all) to 5 (very much) at two time points: one week before the game session and immediately after the escape room. In response to the question “How knowledgeable do you feel about the energy transition?”, the sample achieved an overall mean score of 1.89 (SD = 1.01) out of a maximum of 5 points on the pretest. Similarly, at the end of the EER session, they were again asked to rate their knowledge of the energy transition on a scale of 1 to 5. In this case, the population obtained a mean score of 2.81 (SD = 0.86).

The mean scores obtained before and after the application of the Escape Room show an increase of almost one point in the mean score initially expressed by the students. To determine whether this increase is statistically significant, a paired samples t-test analysis was conducted, resulting in a two-sided significance value of 0.00 and a test statistic of t = 3.84.

5.3 Motivation and Engagement

In order to determine the possible impact of the escape room on the motivational factor, students were asked the question "How motivated are you to learn more about these issues?" before and after the educational intervention, using a similar methodology to that presented in the knowledge section.

In this case, the students obtained quasi-identical mean scores at both moments, with values of 2.97 (SD = .17) before playing the escape room and 3 (SD = .21) after the experience. Similarly, the paired samples t-test does not reflect the presence of statistically significant variations, as it reaches a bilateral significance value of 0.89.

On the other hand, after the escape room, students were asked to rate "To what extent do you think this was an engaging learning experience? For this question, the mean score for the whole sample was 3.47 (SD = .88) out of a maximum of 5 points.

The Kuskal-Wallis and ANOVA tests for the inferential analysis of group differences were carried out in order to avoid statistical errors of the alpha and beta type in relation to post-test motivation and the degree of engagement mentioned by the students; however, no significant differences between the groups were obtained, since both tests reached a significance of p = .28 and p = 27, respectively. Similarly, bilateral correlation tests were carried out between these variables, which again resulted in non-statistically significant coefficients for both Spearman's Rho (p = .21) and Pearson (p = .21), indicating the absence of a correlation between motivation to learn and perceived engagement after the intervention.

5.4 Soft Skills

With regard to the use of soft skills, students were asked at the end of their training experience "to what extent do you think you have used the following skills" and were given a list of 9 items to rate from 1 (not at all) to 5 (a lot).

More specifically, as can be seen in Table 2, more than two thirds of the student population consider that they have used the skills of teamwork (73.7%), problem solving (71%) and communication (68.4%) to a great or very great extent (scores of 4-5), and these are therefore the skills with the highest average scores. At the other extreme, however, are time management and empathy, for which around half of the population (43.8% and 40% respectively) consider that they did not use them during the game or used them to a very low degree (scores 1-2), which is why these variables receive the lowest average scores.

Table 2: Soft skills used during the EER

Items	Response %					Mean	SD
	1	2	3	4	5		
Teamwork	0	0	12.5	50	37.5	4.25	.67
Creativity	3.1	6.3	21.9	34.4	34.4	3.91	1.06
Critical Thinking	0	3.1	25	31.3	40.6	4.09	.89
Communication	0	0	15.8	40.6	40.6	4.22	.75
Time Management	9.4	34.4	25	15.6	15.6	2.94	1.24
Logic	0	9.7	22.6	32.3	35.5	3.94	1
Concentration	0	9.4	25	40.6	25	3.81	.93
Problem Solving	3.1	3.1	9.4	34.4	50	4.25	.98
Empathy	15.6	25	28.1	21.9	9.4	2.84	1.22

5.5 Main Learnings Related to the Energy Transition, What Worked Well and What Didn't Work so Well

To further explore the cognitive effects, students were asked (open-ended question) to describe anything new they learned from the escape room experience in relation to the energy transition. Out of the 32 participants, 23 responded to this question. Segmenting the responses using Thematic Analysis resulted in 33 extracts. An inductive method was used for initial coding, resulting in a total of 12 codes (e.g. Solar, Appliances, Hydrogen, Complicated, etc.). These codes were then grouped into 3 themes, from which 2 key themes related to the research question were extracted and the theme labelled as "miscellaneous" was removed. Table 3 displays the 6 sub-themes and 31 extracts resulting from the 2 remaining key themes. The table also includes the frequency of occurrence and examples of extracts.

Table 3: Themes and sub-themes of participants' new learning about energy transition due to the EER, from most to least represented

Key themes	Frequency of occurrence	Sub-themes	Frequency of occurrence	Examples of responses
Positive learnings about energy transition	27	Learnings about energy consumption	16	"How some appliances might 'look' like they don't consume much energy, but they do" "Small appliances can consume more energy than I can imagine" "How much electricity consume some appliances we use frequently" "How much energy consume the appliances" "That appliances use more energy than I thought"

Key themes	Frequency of occurrence	Sub-themes	Frequency of occurrence	Examples of responses
		Learnings about energy production	7	"How solar panels and wind energy work" "Was a nice way to learn about solar [panels]" "How solar panels work" "How solar/wind powers are connected" "[I learned about] energy production" "How solar panels work"
		Learnings about energy conversion	2	"The concept of how to use hydrogen to generate energy" "[I learned about] energy conversion"
		Learnings about energy in general	2	"[I learned about] the different aspects of energy" "[I learned] more about energy"
Negative learning outputs about energy transition	4	Lack of learnings	3	"I think we didn't come that far to learn anything new" "I didn't learn a lot" "I'm not aware of energy at all"
		Learnings about topic complexity	1	"I learned that [energy transition] it's very complicated"
Total number of responses	31			

To explore which factors could have influenced their perception on learning experience, we asked what worked well and what didn't in the EER; students were asked two open-ended questions. In response to the first question about what worked well, 22 out of 32 participants provided answers. The answers were segmented for Thematic Analysis, resulting in 22 extracts. An inductive method was used for initial coding, resulting in a total of codes such as Educational, Communication, Teamwork, Originality, etc. These codes were grouped into 5 key themes relevant to the research question and 10 sub-themes. Table 4 shows the frequency of occurrence and examples of extracts from these themes and sub-themes.

Table 4: Themes and sub-themes of what participants think worked well about the EER, from most to least represented

Key themes	Frequency of occurrence	Sub-themes	Frequency of occurrence	Examples of responses
Engaging educative resource	6	Engaging	3	"The concept itself is outstanding and could motivate" "It was original and motivating" "It's interesting and engaging"
		Fun or engaging way of learning	2	"Incorporate educational information into engaging activities" "It is a fun way of learning"
		Educational resource	1	"Agreed with the above question that this was educational"
Puzzles about energy transition	6	Energy transition real-life applicability through puzzles	3	"Yes [I think it worked well], especially when it shows the impact of everyday items" "It makes you more aware of your energy usage" "Practical science linked to everyday reality"
		Energy consumption puzzle	2	"The way of measuring the Ampere [of appliances]" "First task [about energy consumption]"

Key themes	Frequency of occurrence	Sub-themes	Frequency of occurrence	Examples of responses
		Energy conversion puzzle	1	"The last task [about energy conversion]"
Use of soft Skills	6	Teamwork	3	"Working as a team" "Working as a team" "Teamwork"
		Communication	1	"The communication part [with the team]"
		Problem-solving	1	"Problem-solving to resolve puzzles"
		Soft skills in general	1	"Using everyday skills to complete puzzles and problems"
Focus on energy transition	2			"The focus on the topic was very clear" "The contents about energy transition"
General negative view	2			"Not much [worked well]" "I would have liked to learn more"
Total number of responses	22			

In response to the second question about what didn't work so well, 26 out of 32 participants provided answers. The answers were segmented for Thematic Analysis, resulting in 39 extracts. An inductive method was used for initial coding, resulting in a total of codes such as Difficult, Morse code, Time, etc. These codes were grouped into 4 key themes relevant to the research question and 6 sub-themes. Table 5 shows the frequency of occurrence and examples of extracts from these themes and sub-themes.

Table 5: Themes and sub-themes of what participants think didn't work well about the EER, from most to least represented

Key themes	Frequency of occurrence	Sub-themes	Frequency of occurrence	Examples of responses
Criticism of the overall design of the Escape Room	23	Excessive difficulty	10	"The tasks were too hard for what we are used to." "The difficulty was a bit high" "Difficult" "It was too difficult" "Difficult questions"
		Requires clearer explanation and guidelines	10	"[Needs] Better written content and guidelines" "The guidance" "A better explanation is needed" "Some puzzles were confusing or very unclear" "Understanding what was useful and what was a distraction"
		Insufficient time	3	"Some activities required more time we had" "We hadn't enough time" "Managing the time"
Broken tools or materials	7	Broken tools or materials in general	4	"I think that my experience was negatively impacted by the fact that some things where not functional" "Some things were broken" "Some of the puzzles were broken" "Some puzzles were broken"
		Broken tools on Energy	3	"The watt-meter didn't work properly, so we couldn't solve the code"

		consumption puzzle		"One tv (big one) wasn't showing the real indicators so we got stuck in the first part about 40 minutes" "Problem with one of the watt reader"
Criticism of the Energy production puzzle	5			"The morse code" "Morse code should be more beginner friendly so the learning is more fun" "Difficult morse code (stuck there)" "It should be less complicated because not everyone knows about morse code" "The second task [which used the morse code]"
General positive view	2			"Everything was well thought out" "It was interesting"
Total number of responses	37			

As a summary, figure 4 shows the different intra- and inter-theme and sub-themes connections of the three open-ended questions analyzed.

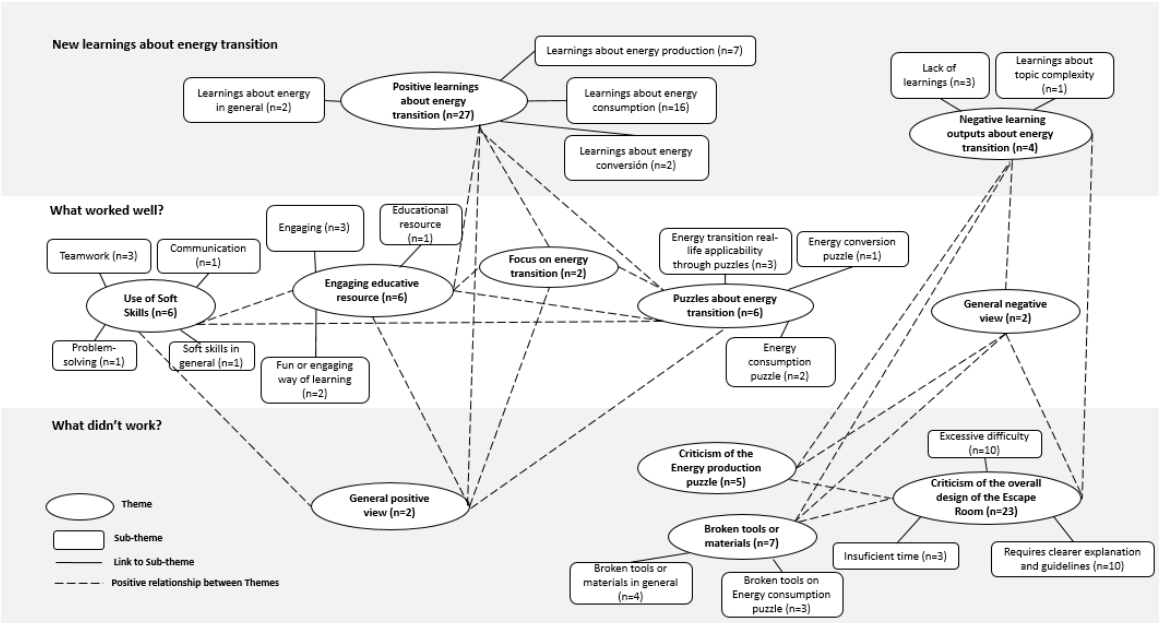


Figure 4: Relationships between the themes and sub-themes in the three open-ended questions

6. Discussion

In higher education institutions, there has been an increase in the use of educational escape rooms (EER) in recent years. However, there has been little research conducted on the topic of energy transition, and even less on the design of escape rooms by students for students. This is particularly pertinent given that: a) young people possess a significant capacity to assume an active role in the energy transition; b) there is a lack of strategies that align with their needs as the interactive generation, to motivate them to learn more about energy transition; (c) teachers are typically in charge of developing materials for students, without considering the potential of youth as agents of change; (d) there is a paucity of evidence regarding the effects of EER designed by students on the complex topic of energy transition. These are some of the reasons why this study is needed, and it provides to the academic debate on the topic of EER.

6.1 Playing an EER Significantly Increases Players' Knowledge About Energy Transition

The results of self-perceived knowledge on energy transition demonstrate a statistically significant increase within the group prior to playing the EER in comparison to the values obtained subsequently. This resulted in an increase in the average mean value for energy transition knowledge by 48.68%. These results alone could indicate a positive effect of the EER on knowledge acquisition. However, it is also possible that the students themselves concluded after the experience that their knowledge was higher than their initial estimation. To test this hypothesis, a thematic analysis of the open-ended question on new learning related to energy transition was conducted. The results demonstrated that in 27 out of 31 extracts (87.10%), respondents reported acquiring new knowledge on the subject after playing the EER. Subsequently, sub-themes were delineated, and it was determined that the most prevalent areas of emphasis were learning about energy consumption (51.61%), energy production (22.58%) and energy transformation (6.45%). Furthermore, explicit references to this area also appear in the open-ended question regarding the factors that have contributed to the success of the EER. In this section, over two-thirds of the extracts (63.64%) expressed a positive view of the EER as an educational and enjoyable method of learning (27.27%), highlighting their positive perception of the energy-related puzzles (27.27%) and the clear focus on the energy transition theme (9.09%). Therefore, both quantitative and qualitative data from the study indicate that playing an energy transition EER significantly increases players' energy transition knowledge. These results are consistent with those of the systematic review by Veldkamp *et al.* (2020) and the pretest-posttest studies by Fusco *et al.* (2022), Clauson *et al.* (2019), López-Pernas *et al.* (2021), and Eukel *et al.* (2020), which demonstrate that EER methodologies have the potential to enhance participants' knowledge after playing.

6.2 Motivation to Learn About Energy Transition is not Influenced by the EER, nor is it Highly Correlated to Engagement

The data on motivation to learn about the energy transition indicates that the players exhibited an intermediate level of motivation on average prior to playing the EER, with a score of 2.97 on a scale from 1 (low) to 5 (high). After playing the EER, this level of motivation was almost perfectly maintained, with an average score of 3 points on the second measure. Consequently, in contrast to the cognitive domain, the EER intervention did not result in a significant difference in motivation to learn about the energy transition in this sample. These results diverge from expectations, particularly in the context of extensive literature reviews such as those by Hayden *et al.* (2022) and Zainuddin *et al.* (2020), which indicate that, in the majority of the reviewed articles, EERs and gamification demonstrate a high motivational potential.

The results of the player engagement survey indicate an average score of 3.47 out of 5 points. This score deviates from the observed neutrality of motivation, suggesting a positive evaluation of the players' engagement with the EER. Furthermore, it is noteworthy that in the responses to an open-ended question regarding what aspects of the EER were perceived to be effective, 27.27% of the responses explicitly referenced the EER as an engaging and enjoyable learning resource. Both results indicate a favorable assessment of the EER as a resource that fosters player engagement. This finding aligns with previous research on EERs, which has demonstrated that these types of resources effectively retain players' attention and motivate them to continue playing, while simultaneously providing enjoyment (Duncan, 2020; Garwood, 2020; Healy, 2019; Ross and Bennett, 2022). However, despite these encouraging outcomes, further improvement is possible, particularly in terms of engagement levels. While the open-ended questions indicate that players are generally positive about the EER experience, the engagement scores are relatively moderate.

Numerous studies and theories suggest that this type of methodological resource is one of the most inherently motivationally effective among the young population, usually perceived as a highly engaging experience presents (Handayani, Hayden *et al.*, 2022; Raffani and Hadi, 2021; López *et al.*, 2019; Taraldsen *et al.*, 2020; Vidergor, 2021; Wam, King and Chan, 2021; Zainuddin *et al.*, 2020). However, the inferential analyses conducted between motivation to learn about the energy transition and players' perceived engagement revealed the absence of statistically significant results regarding possible group differences. Furthermore, the correlation between these variables was observed to be very low, suggesting that motivation to learn, either before or after the game, and perceived engagement during the EER are not highly correlated. The divergence between the literature and the results of this study appears to be due to two main factors. Firstly, the majority of studies appear to focus on motivation to play or to continue playing rather than motivation to learn. Consequently, there is a lack of substantial literature that examines the relationship between perceived engagement and motivation to learn about the educational topic that the designer intends to teach. Secondly, as hypothesized by Veldkamp *et al.* (2020) in their systematic review, it is possible that some researchers have misinterpreted increases in players' motivation to play or complete the EER as an increase in intrinsic motivation to learn. Further investigation is required to ascertain whether these findings can be replicated.

6.3 Participation in an EER Fosters Soft Skills Development, Particularly Those Related to Teamwork, Problem-Solving, and Communication

The results demonstrate the potential of EER for the practice and development of the nine soft skills explored in the study (ranging from 1 to 5). None of the skills obtained an average score close to 1, which would have suggested their absence of use during the game. Therefore, it can be concluded that all of the studied skills were used to some extent during the game. These findings are consistent with those of Cai (2022), Taraldsen *et al.* (2020), and Ouariachi and van Dam (2022), who have identified EER as a means of developing and enhancing numerous soft skills.

A more detailed analysis of the different soft skills assessed reveals that teamwork (4.25), problem-solving (4.25) and communication (4.22) have the highest mean scores for the sample. It is also noteworthy that this mention of the three soft skills also appears in the thematic analysis, in response to the question on what worked well on the EER. In this context, players indicated the use of these soft skills (27.27%), specifically teamwork (13.64%), problem-solving (4.55%) and communication (4.55%) in the extracts. These findings provide further support for the conclusions of previous systematic reviews, including those conducted by Quek *et al.* (2024), Hintze, Samuel and Braaten (2023), and Veldkamp *et al.* (2020), and are also consistent with those of Huang, Kuo and Chen (2020), Duncan (2020), and Whitton (2018), who conducted quasi-experimental research and found that EER resources are particularly conducive to the development of teamwork, problem-solving and communication.

The soft skills that players reported using the least during the EER were empathy (2.84) and time management (2.94). Empathy is an interpersonal and social skill with a high value in dynamics and relationships between people, as it can help groups to become closer and encourage teamwork and communication (Jung, Lee and Lim, 2023). In this case, high levels of teamwork and communication are observed, accompanied by low average scores in the use of empathy by the players. It is hypothesized that this situation may be due to the fact that the groups of players worked collaboratively and got along well during the EER. Consequently, there have been few instances in which the Empathy skill was required, as it is typically elicited in situations perceived as unpleasant or negative in others (Jung, Lee and Lim, 2023). The low score obtained in time management is somewhat anomalous, given that ERs are typically games against the clock in which players must perform a series of tests to escape in a given time. Consequently, this skill should be utilized to a greater extent. In EER, the duration of the game must be clearly defined and be realistic. It should be sufficiently long to prevent frustration among participants, yet short enough to provide a motivational incentive to advance and teamwork (Veldkamp *et al.*, 2020). Therefore, a low perceived use of time management may be due to two situations: it is hypothesized that a low perception of time management use among players may be due to three situations, namely: a) in the event that play time is sufficient or even excessive, and difficulty is low or intermediate, it can be argued that this represents a design problem. In such a case, it would be advisable to either increase the difficulty or reduce the play time; b) alternatively, if play time and difficulty are deemed to be adequate in design, but players have not managed their time well, this could be considered a problem of poor time management rather than a design issue. However, the issue may be more complex than this, as the player type itself may also be a contributing factor; c) another possibility is that the playing time is short and the difficulty is too high. This could lead to a negative perception of the time management skill due to design problems. In such a case, it may be necessary to either reduce the difficulty or extend the playing time. In order to address this hypothesis, the following section will analyze the design of the EER.

6.4 Key Aspects of Good EER Design: Balanced Difficulty and Playtime, Along With the role of in-Game Guidance and Puzzles With Real-World Applications

Thematic analysis of the open-ended questions, especially those related to what worked well and what did not work well in the EER, reveals some of the strengths and weaknesses in designing the EER. Some of the strengths related to the design have already been discussed above, particularly those related to the positive perception of the energy consumption-related puzzles (27.27%) and the clear focus on the energy transition theme (9.09%). However, it is also important to consider the factors mentioned by students when asked what didn't work so well: general complaints about the overall design of the EER (62.16%), some puzzles broke during play or presented some problems (18.92%) and others (Morse code puzzle 2 in particular) were perceived as very difficult (13.51%). The general criticism of the EER design can be divided into three sub-themes: excessive difficulty (27.03%), insufficient explanations and guidance during the game (27.03%), and insufficient time to complete the game (8.11%). Perceived overly difficult tasks may lead to needing more guidance from the facilitator or narrative material, and also to lack of time to complete them. Similarly, overly difficult tasks or confusion about what needs to be done to complete them may lead to feelings of time pressure. Finally, asking for more explanation or guidance may be related to overly complex tasks or running out of time. The importance of an appropriate level of difficulty and playing time is consistent with the findings of Veldkamp *et al.* (2020) in their systematic review, where they state that these aspects of design need to be fine-tuned to achieve the desired outcomes for players. Furthermore, Quek *et al.* (2024) return to the same ideas in their systematic review four years later, while adding another nuanced point: "the learners' negative reactions of EER on the time constraints, lack of guidance and lack of useful cues highlighted the crucial role of facilitator to ensure the team progression in the game" (p.7). This aspect is crucial for the present study as the facilitator who conducted the EER was a student volunteer, rather than a more experienced EER practitioner with more knowledge of the puzzles and more resources to know when and how to give hints or guidance when players got stuck in the quizzes. Difficulty, time and guidance therefore form a triangle that should be at the center of the design, testing and adaptation of any EER in order for it to be of high quality.

Finally, the design aspects of the different puzzles that make up this EER are analyzed in more detail. The open-ended questions on the energy-related puzzles yielded significant findings regarding EER design aspects: 1) The *Energy Consumption* puzzles were found to be effective in teaching new concepts and generating a positive perception of energy efficiency. Several participants expressed surprise at the difference between the expected consumption (based on popular knowledge) and the actual consumption (based on scientific knowledge) of the appliances they use on a daily basis. This situation may have stimulated greater interest and facilitated learning. Although there are some criticisms, these are mainly due to accidental problems in the measurement system; 2) the *Energy Production* puzzles generate interest in learning about solar energy and wind turbines. However, the lack of positive mentions and numerous negative mentions towards "Morse code" suggest design or difficulty problems that should be considered for future editions; 3) the *Energy Storage* puzzles lacks significant mentions in any of the three aspects studied, suggesting that it does not adequately fulfil its educational role in relation to the energy transition.; 4) the *Energy Transformation* puzzles receives less attention in terms of learning and does not stand out positively or negatively in the players' view. Therefore, it is planned to rethink this puzzle to make it more impactful. These results of the design analysis of the puzzles suggest that those puzzles that show a clear extrapolation to everyday life are the most effective for teaching about the energy transition through the EER.

7. Conclusions

The study examines the impact of a student-designed educational escape room (EER) to teach about the energy transition, a topic that is not widely addressed. The main findings in the knowledge domain indicate a significant improvement in the self-perceived knowledge about the energy transition after the participation in the EER. Specifically, the thematic analyses show that the main areas of new learning are related to consuming, producing and transforming energy. It should be noted that the aforementioned findings are contingent upon the EER employed in this study. However, they are consistent with, and contribute to, those expressed by various authors in studies and systematic reviews confirming the educational potential of EERs. However, to the authors' knowledge, no studies have been identified that evaluate the impact of EERs in the energy transition. This highlights the relevance of the findings and provides an opportunity for further research in an area where there is little evidence of the impact of this pedagogical methodology.

The results regarding motivation to learn about the energy transition show that the EER employed in this research does not significantly affect this, either positively or negatively. The mean scores are almost identical between the pre- and post-EER tests. In addition, the level of engagement reported by the players is slightly lower than expected. These findings differ from what would be expected based on literature review such as those by Hayden *et al.* (2022) and Zainuddin *et al.* (2020), which highlight the motivational potential of EER and gamification in education. Furthermore, the correlation between learning motivation and players' perceived engagement is almost non-existent. This trend contradicts previous studies (Vidergor, 2021; Wam, King and Chan, 2021; Zainuddin *et al.*, 2020). However, it is consistent with the hypothesis of Veldkamp *et al.* (2020) in their systematic review of EER, in which they suggest that researchers may have confused motivation to learn and motivation to play or win in their studies. More research along these lines is needed to test this further.

The results show how the EER employed enhances, to a greater or lesser extent, the implementation and development of all the soft skills examined. These findings are in line with those of Cai (2022), Taraldsen *et al.* (2020) and Ouariachi and van Dam (2022), who have identified EER as a means of developing and enhancing numerous soft skills. Similarly, it is observed that teamwork, problem solving and communication are the soft skills that players most perceive as being put into practice during EER, and are therefore the most required and worked on during the game session. It is also clear from the thematic analyses that these skills are not only the ones that are most in demand, but are also the ones that students value most. Thus, the quantitative results confirm the trend observed in the existing academic literature on the subject, while the qualitative results add a so far unexplored nuance to the situation: the use of teamwork, problem solving and communication is positively valued by the players.

Strengths and weaknesses in the design of the EER emerge from the thematic analysis of participants' comments. While some strengths include a positive perception of the energy consumption-related puzzles and a clear focus on the issue of energy transition, weaknesses such as difficult tasks, insufficient explanations and time constraints were also identified. These findings underscore pivotal considerations in the design of any EER, such as the importance of adjusting difficulty, playing time and guidance to optimize the player experience, as reported in previous systematic reviews such as Veldkamp *et al.* In addition, the role of the facilitator is crucial in supporting the team's progress and providing help when needed. These three aspects represent a triangle on which the design trade-offs of any EER should focus in order to increase its quality and improve the players' game experience. Furthermore, the four puzzles that make up the EER differ in their pedagogical impact and design quality when analyzed individually. A special mention should be made of the idea that puzzles that are closely related to everyday life have a greater impact on the learning of the energy transition.

After the conclusions have been drawn, the limitations of the study and the directions for future research will be the subject of discussion. With regard to the limitations of the study, it should be noted that the design flaws of the EER, which is still a prototype designed and facilitated by students in the game sessions, may have influenced the results obtained in the study. Therefore, caution should be taken when generalizing the conclusions of the study, especially those that are not consistent with previous articles and systematic reviews. Similarly, the use of an ad hoc questionnaire may also make it difficult to generalize the conclusions obtained, although it may have advantages in exploring specific aspects, such as the evaluation of the design of the EER. This was a novel aspect of the present research due to the scarcity of literature on the subject.

With regard to future lines of research, the aim is to improve the design of the EER used in this research, based on the results and conclusions drawn, in order to check whether the improvement options observed serve to increase the impact of the EER in all the aspects explored in the research and/or whether different results are obtained from those observed. On the other hand, it also highlights the opportunity to further explore the findings on the lack of impact of EER on motivation, specifically on motivation to learn and its correlation with engagement.

The importance of the overall quality of EER design and its impact on learning outcomes, motivation and interpersonal skills could also be investigated in future studies. This would include factors such as the level of difficulty, timing and orientation of the game. Another line of research could be to compare traditional teaching methods such as lectures with active methods such as EER, which could reveal differences in the use of cognitive, motivational and social skills. Furthermore, a comparison of student-designed EER with professionally-designed EER, which have higher quality immersive elements and professional game animators, could provide valuable information.

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