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

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https://doi.org/10.34190/ejel.22.4.3186

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).

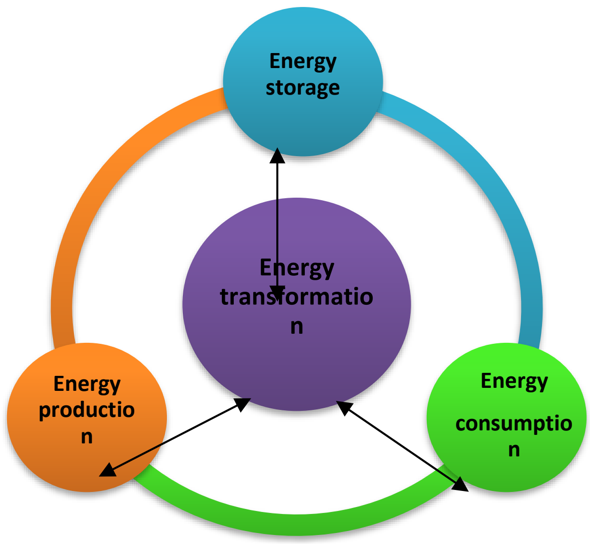
The application of recreational escape rooms for educational purposes has become increasingly popular as a means of engaging young people in their learning environment. This approach is designed to encourage the development of both hard skills and soft skills, including critical thinking, collaboration,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

Cite this article: González-Muñoz, E. and Ouariachi, T. 2024. "Unlocking Learning: The Impact of an Educational Escape Room on Energy Transition", *The Electronic Journal of e-Learning*, 22(4) pp 57-74, https://doi.org/10.34190/ejel.22.4.3186

(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.

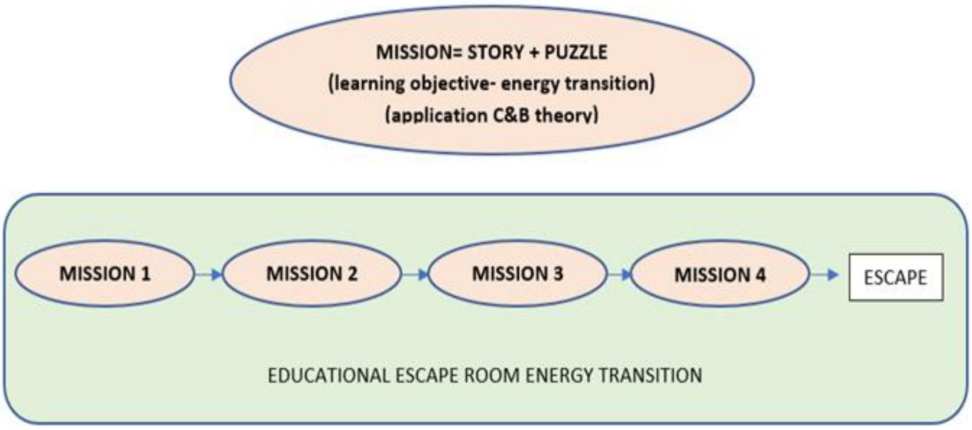


Figure 3: Escape room set-up

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.

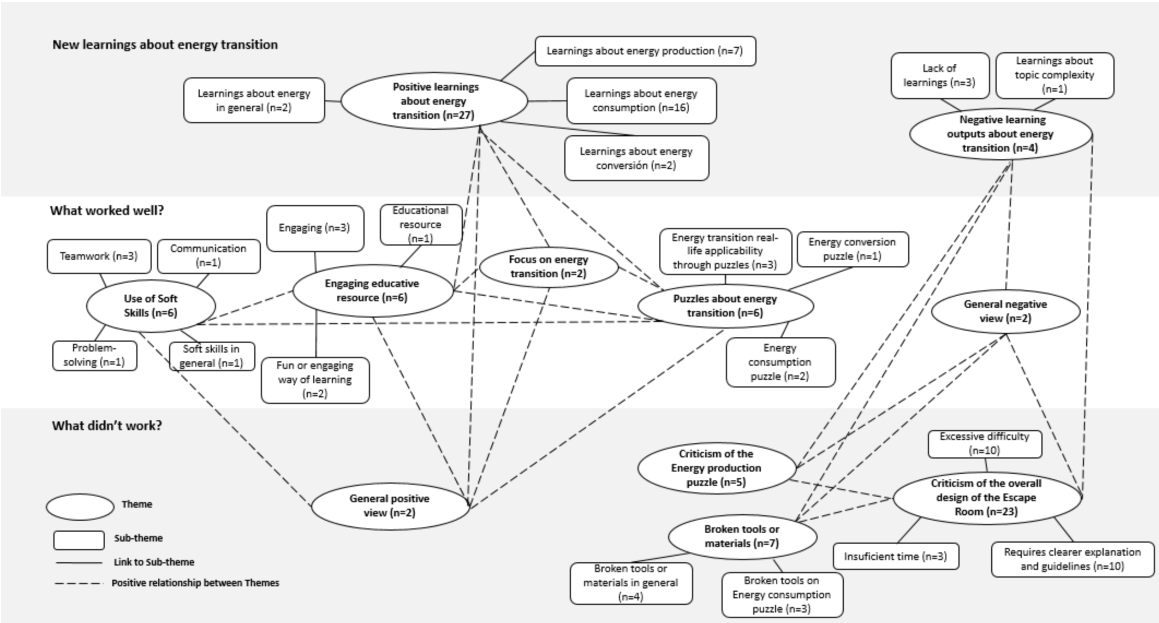


Figure 4: Relationships between the themes and sub-themes in the three open-ended questions

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.

Acknowledgements

This research was supported by Project (PID2022-136933OB-C22) 'Educar a tiempo: formación disruptiva y recursos pedagógicos de calidad como catalizadores del cambio climático' RESCLIM@TIEMPO funded by MICIU/AEI /10.13039/501100011033 and by ERDF, EU. Comenius Teaching Fellowship / Netherlands Initiative for Education Research (NRO) and the Centre of Expertise Energy (Hanze University of Applied Sciences). Grant FPU20/03615 funded by MICIU/AEI /10.13039/501100011033, FSE invierte en tu futuro, and the University of Granada.

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