STEAMscapers: A Digital Escape Room Scenario Based on STEAM and Project-Based Learning

Michael Bouskos, Foteini Paraskeva
Department of Digital Systems,
University of Piraeus,
Karaoli & Dimitriou 80, Piraeus,
Greece

Received: March 26, 2025. Revised: June 29, 2025. Accepted: July 22, 2025. Published: April 17, 2026.

Abstract— Digital educational escape rooms have emerged over the past decade as an innovative, game-based learning approach. Although interest in escape rooms is steadily increasing, the literature shows a lack of a widely accepted methodological framework for their design and implementation in educational settings. In this context, the present study integrates Project-Based Learning with the STEAM approach through the use of a well-designed educational scenario called 'STEAMscapers'. This scenario is implemented within an e-learning environment, using Web 2.0 technologies and the escape room format to assess the effectiveness of a pedagogically designed solution hosted on the WIX platform. The innovative aspect of this research is that STEAMscapers represents the first fully developed instructional scenario that combines both STEAM and Project-Based Learning within a digital escape room environment. To assess its effectiveness, a quantitative study was conducted with a sample of 40 e-learning experts. The research focused on six key effectiveness dimensions, referred to as Key Performance Indicators (KPIs). The results were highly positive, with participants rating the escape room as very effective—particularly in terms of content quality and interactivity—and also giving high scores in other areas, such as assessment, learning outcomes and course organization. The study concludes that digital escape rooms, combining Project-Based Learning with the STEAM approach, can be effective educational tools for primary education.

Keywords— e-learning, escape room, Project-Based Learning, STEAM, STEAMscapers.

I. Introduction

Modern education must align with the needs and demands of the 21st century. Therefore, it is essential to cultivate students equipped with the necessary skills to respond effectively to the challenges of today's society. In this context, the development of skills such as problem-solving, critical thinking, self-regulation and collaboration—commonly referred to as 21st-century skills—is of utmost importance [1], [2].

An increasingly popular educational approach in this area is STEAM, which breaks down traditional disciplinary silos in Science, Technology, Engineering, Arts, Mathematics and reconfigures them into an integrated curriculum [3], [4]. STEAM education is recognized as one of the most prominent educational movements in recent years. STEAM embraces the idea of inquiry-based learning where students are allowed to create their own ideas by participating in a variety of problem-solving activities [5], [6]. To achieve its goal of developing students as well-rounded learners who function in a rapidly evolving technological and multi-disciplinary environment, STEAM focuses on the holistic construction of knowledge through multiple methods of learning and application [7].

This method helps students develop their creativity, critical thinking, inquiry and problem-solving skills. It also supports the development of students' collaboration and communication skills [4], [8], [9]. As a result, STEAM education prepares students for success in an increasingly science and technology-driven society [10].

STEAM educational approach needs to be accompanied by a learning model that allows students to connect the information they have learned with its practical use. Literature indicates that Project Based Learning (PjBL) provides a suitable pedagogical model to implement STEAM [11], [12], [13], [14], [15].

Project-Based Learning is a student-centered teaching method that uses projects as the central aspect of learning through inquiry-based learning [14], [16], [17], [18]. It emphasizes students' active involvement in problem-solving, designing and creating work [19]. Typically, project-based learning is structured around a central question developed by the teacher. It encourages student collaboration, incorporates supportive technologies and focuses on critical thinking, communication skills and interdisciplinary learning [20]. As illustrated in Fig. 1 and as referenced in [21], Project-Based Learning is organized into three fundamental stages: Planning, creation and reflection or editing.

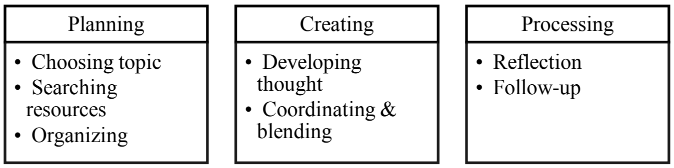

Fig. 1 The 3 phases of Project-Based Learning
Source: [21]

In recent years, there has been a growing interest in the utilization of escape rooms within educational contexts due to their potential to augment the learning process [22]. Consequently, educational escape rooms have emerged as an innovative, game-based pedagogical approach. These environments integrate teamwork and problem-solving with storytelling and mystery elements [23]. They are founded on constructivist theory, which posits that learners acquire knowledge more effectively through active participation and meaning making via experience [24], [25].

In this format, students are challenged to solve a series of puzzles to "escape" from a simulated environment, creating an active, learner-centered educational experience. Educational escape rooms feature activities designed to teach knowledge or develop specific skills. This is achieved through the resolution of puzzles that are directly linked to well-defined learning objectives. The goal is not always to escape a physical room. For this reason, digital tools are often employed to create hybrid learning environments that simulate a physical escape room experience. Digital educational escape rooms have been integrated into various academic disciplines, including health sciences, STEAM and computer science, primarily in higher education contexts [26].

Studies have demonstrated that virtual escape rooms can enhance student motivation, foster critical thinking and improve problem-solving skills [27], [28]. Furthermore, they transform learning into a fun and immersive experience and increase student involvement in the educational process [22], [26], [29], [30], [31]. Some studies also indicate that educational escape rooms lead to better learning outcomes, [31].

In summary, escape rooms have become an innovative educational tool, with their virtual versions gaining significant popularity in recent years, especially due to the COVID-19 pandemic [25].

II. PROBLEM FORMULATION

Although STEAM education is gaining increasing popularity, the literature indicates certain inconsistencies. Specifically, there is a lack of clearly defined instructional practices to guide STEAM teaching. Many scholars emphasize the need to develop a well-defined conceptual framework that clearly states the core principles of the STEAM approach [6], [32]. Furthermore, despite documented positive outcomes from combining STEAM with Project-Based Learning, this integration has not been thoroughly examined within the context of online learning [11], [19], [33]. Regarding escape rooms, it is evident that their use in educational settings has not been comprehensively investigated. Only a few studies provide detailed descriptions of their implementation in educational settings and even fewer focus specifically on primary education [23], [26], [29], [34].

Additionally, several researchers argue that existing studies often lack rigorous research design—particularly in data collection and analysis methods—highlighting the need to develop frameworks for designing and evaluating educational escape rooms [30], [34]. Another major limitation is that escape rooms are typically used as supplementary classroom activities, introduced either at the beginning or end of a lesson to boost student engagement and promote collaboration [30]. This suggests that escape rooms currently serve mainly a supporting role and cannot yet replace formal instruction. Finally, it is essential to note that no published studies have specifically linked escape rooms with the STEAM approach and Project-Based Learning in primary education [14].

Considering the above, designing an educational escape room is deemed necessary and it should:

- Integrate STEAM education with Project-Based Learning.
- Develop entirely within a digital learning environment.
- Serve as a comprehensive instructional scenario rather than a supplementary activity.
- Conduct an experimental study to evaluate the effectiveness of escape rooms in STEAM

III. METHODOLOGY

A. *Research questions*

Based on the above, the following research questions were formulated:

- RQ1: How effective is a digital escape room based on the STEAM approach and Project-Based Learning as a learning experience for sixth-grade primary school students, according to the following e-learning quality dimensions and their respective KPIs?
    - RQ1.1: Learning Outcomes
    - RQ1.2: Course Introduction and learning activities
    - RQ1.3: Assessment and measurement
    - RQ1.4: Interaction and feedback
    - RQ1.5: Content quality and interactivity
    - RQ1.6: Course organization

- RQ2: Are there statistically significant differences in participants' evaluations across the six

'STEAMscapers' effectiveness dimensions?

- RQ3: What are the statistically significant correlations among the six 'STEAMscapers' effectiveness dimensions and how do these associations reflect the coherence of the learning experience as perceived by participants?

B. Research Design

To evaluate the effectiveness of an escape room that combines STEAM and Project-Based Learning, a comprehensive instructional scenario in the form of a digital escape room—titled STEAMscapers—was designed and developed within a Web 2.0 environment. STEAMscapers was implemented using the WIX platform, which was customized to include various digital tools and educational resources.

The escape room is centered on the theme of renewable energy sources. Students are informed that there has been a significant blackout and that they are locked inside their school. To escape, they must unlock the main electric door by designing and constructing a device capable of generating electricity using renewable energy sources. To complete the challenge, students need to unlock seven different virtual rooms. In doing so, they must search for clues, collaborate, solve quizzes and create original projects by applying the STEAM approach.

To evaluate the learning effectiveness of the escape room as an instructional tool, a preliminary assessment was performed involving a group of experts before its integration into the classroom setting. Accordingly, a quantitative research methodology was employed, utilizing a structured digital questionnaire. The questionnaire was given to the participants after their guided walkthrough of the escape room, which was supervised by the research coordinator.

C. Sample

The sample consisted of 40 experts in the field of e-learning, selected through a random sampling method.

D. Research tools

To evaluate the perceived effectiveness of STEAMscapers, a custom questionnaire with 22 closed-ended items was created, based on the eight e-learning quality dimensions proposed in [35]. As shown in Table I, these dimensions were adapted into six STEAMscapers effectiveness dimensions, each measured through specific Key Performance Indicators (KPIs) designed to evaluate perceived learning quality and effectiveness within the digital escape room setting. The questionnaire items were rated on a five-point Likert scale (1 = "not at all," 2 = "slightly," 3 = "moderately," 4 = "very," 5 = "extremely"), ensuring that all key aspects of learning effectiveness were systematically evaluated.

Initially, a reliability analysis was performed to evaluate the internal consistency of the questionnaire items.

Table I. STEAMscapers Quality and Effectiveness Evaluation Framework

Quality Dimensions by [35]	Associated KPIs	STEAMscapers effectiveness dimensions
Learning Outcomes	Clarity, measurability and consistent linkage during learning and assessment activities.	Learning Outcomes
Course Introduction	Familiarization with course purpose, structure, content access and pedagogical strategies.	Course Introduction and Learning Activities
Learning Activities	Designed for analysis and skill development within a real-world context.	
Assessment and Measurement	Consistency with learning outcomes and objectives; multiple opportunities for learners to track progress.	Assessment and Measurement
Interaction and Feedback	Active learning promotion; use of discussion forums and collaborative assignments.	Interaction and Feedback
Content Quality	Up-to-date, accurate and relevant content; relevant and attractive design.	Content Quality and Interactivity
Multimedia and Interactivity	Use of multimedia elements and interactivity for enhanced learning experiences.	
Course Organization	Clarity and consistency; effective communication of assignment due dates.	Course Organization

Source: adapted from [35]

Table II. Reliability Statistics

Cronbach's Alpha	N of Items
0.891	22

As demonstrated in Table II, the Cronbach's alpha coefficient was calculated at 0.891, indicating a high level of internal consistency and implying that the research instrument is highly reliable.

E. Instructional Design

The instructional design of the escape room was developed through the integration of STEAM and Project-Based Learning. To achieve this, the STEAM-PjBeL model by [36] was used, which is implemented through the following five steps (Fig. 2).

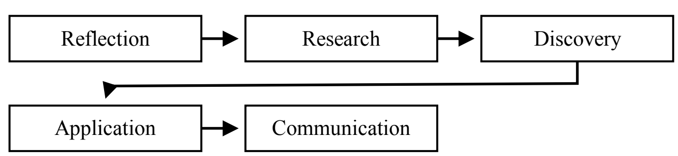

Fig. 2 PjBeL-STEM steps
Source: adapted from [36]

The first stage of the PjBeL-STEAM learning model is Reflection. The goal of this stage is to introduce students to the problem context and connect prior knowledge with new learning objectives [36]. In this phase, students are introduced to the problem and storyline through an introductory video. They are then guided by a digital agent who explains the objectives and structure of the activity. Afterward, students get to know each other via Padlet and participate in a brainstorming activity in pairs using the platform Mentimeter, focusing on renewable energy sources.

The second stage, Research, aims to engage students in active, inquiry-based learning activities. In this phase, students will be working on research activities that are related to the problem. In our scenario students will be divided randomly into four expert groups (solar, water, wind and biomass) using the cooperative Jigsaw method. Each group will be assigned an energy source and then use artificial intelligence (AI) tools like ChatGPT and Gamma AI to research the assigned energy source. After researching their assigned energy source, the students will create a digital presentation that illustrates their findings and post it into the escape room's discussion forum. Afterward, each student will complete a questionnaire to evaluate both their digital presentations and the AI tools used. Finally, students will return to their home groups and present their findings to their classmates. Each student will also complete a quiz to assess their understanding of the content explored in the previous phase (Fig. 3).


Fig. 3 Formative Assessment with Kahoot!

The third stage of the model is Discovery. The goal of this phase is to connect the research done by students with their final project design. At this stage, the STEAM approach is integrated to support project completion and deepen understanding of scientific concepts. In the instructional scenario, students—guided by the digital agent—are divided into STEAM expert teams. They follow various learning paths while exploring one of four specialized rooms: Science, Technology/Engineering, Arts and Mathematics (Fig. 4).

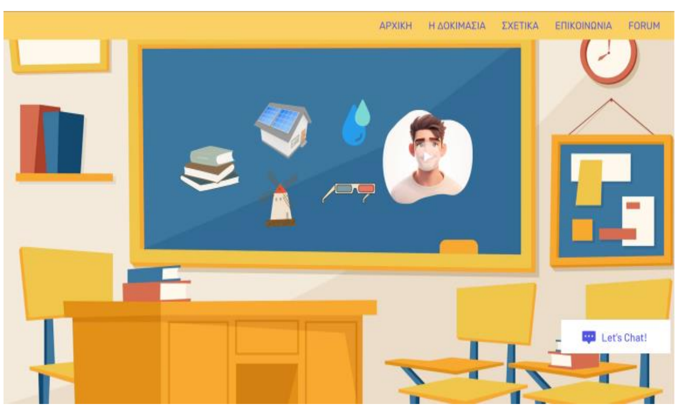

Fig. 4 Mathematics Classroom

Each of these rooms contains hidden objects that students must sequentially investigate. Their exploration involves theoretical activities, interactive simulations, educational videos and quizzes. To unlock one of the STEAM rooms, students need to solve a series of puzzles directly related to the scientific field they have been assigned (Fig. 5). After this stage, students regroup in their original teams to discuss and decide on the project they will build.

Fig. 5 Puzzles in STEAM Classrooms

The fourth stage of the model is Application. This stage allows students to develop a project that addresses and offers a solution to the initial problem. In this phase, students integrate their knowledge using STEAM disciplines. Students will return to their original teams to create one of the following: Waterwheel, Wind Turbine, or Electric Vehicle (Fig. 6). As students work through this process, the educator will monitor student engagement and support students in completing their project. At the end of this stage, students complete a brief questionnaire evaluating how well their construction functions.

Fig. 6 Final Student Projects

The fifth and final stage is Communication. This stage provides students with an opportunity to share their projects with their peers. It is essential that they present their projects to develop both collaboration and communications skills [36]. Presenting allows the participants to discuss and share ideas in a group setting, analyze real-life situations and develop a better understanding of how things work [37]. The students introduce their project to the rest of the class, explaining not only how they completed it, but how it works, as well as what difficulties they faced during the project. Once presentations are completed, all students then evaluate each other's projects using the Mentimeter app in real-time and the most effective designs are recognized. The process concludes with a reflective quiz on their learning journey and the STEAM approach. Students are then told they have completed the escape room challenge and unlocked the school's main gate, earning their certificate of participation.

F. Pedagogical Flow of the STEAMscapers Digital Escape Room

In the given scenario, students are trapped inside the school premises. Their objective is to collect clues and systematically navigate through each room in sequence to ultimately unlock the main door.

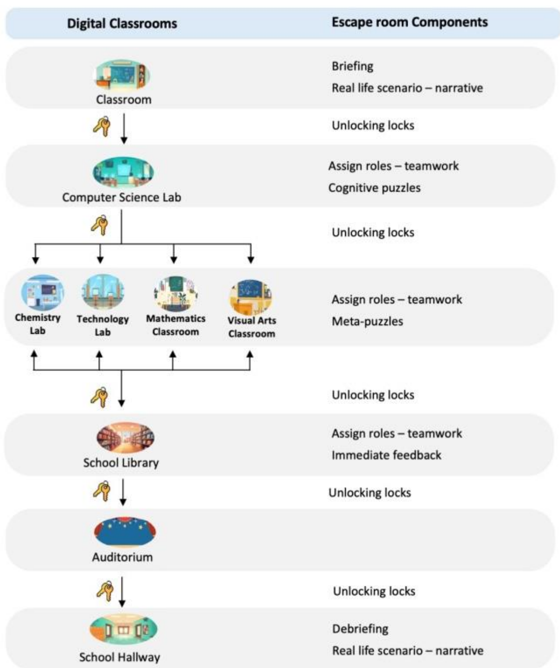

Fig. 7 STEAMscapers Escape Room Structure
Source: created by the authors

As illustrated in Fig. 7, students move sequentially from one room to the next, each unlocking a new stage of the learning model. In STEAM rooms, the puzzle setup uses a multi-path approach. Students are divided into subgroups and search for clues simultaneously, working together to reach the library. From there, the linear sequence of puzzles continues, guiding students step-by-step to leave the school.

G. Interdisciplinary literacy of STEAM

Within the escape room, students apply the STEAM approach by making interdisciplinary connections across the five domains as follows:

a) Science

Students explore basic ideas related to electricity and renewable energy. They investigate how a dynamo works, what its main parts are and how it generates electricity. They also examine different forms of energy conversion and become familiar with systems such as solar panels, wind turbines and hydroelectric power plants.

b) Technology

By interacting with the digital environment of the escape room, students strengthen their digital literacy. As they move through the online platform, search for information, prepare digital materials and experiment with various tools, they gain skills essential for effective technology use in problem-solving situations.

c) Engineering

Students are introduced to simple electrical circuits. They learn how they are structured and what each component does. Using basic materials, they then design and construct their own circuits, creating small functional models that generate electricity from renewable sources.

d) Arts

In the creative phase of the project, students sketch an initial design for their construction. Then they construct physical models of renewable energy systems. This process encourages them to think visually, improve design thinking and express their ideas through artistic choices.

e) Mathematics

Students practice measuring electrical power and learn how to convert between different energy units. They calculate energy output, choose suitable components (such as the right type of lightbulb) and make precise measurements during the construction of their models to ensure everything fits and functions correctly.

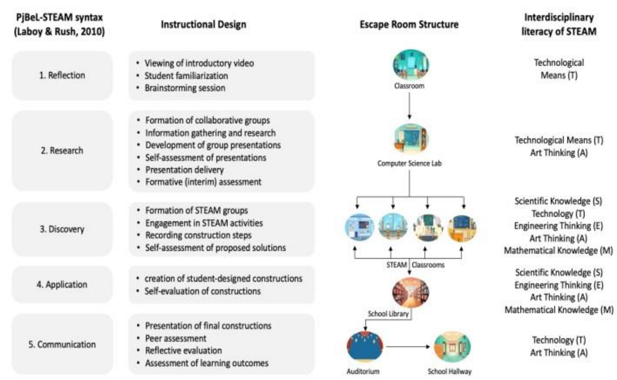

Fig. 8 STEAMscapers Interdisciplinary literacy of STEAM
Source: created by the authors

Fig. 8 shows how the STEAM approach permeates the scenario and relates to the learning model.

H. Educational Value of the STEAMscapers

Based on the above, it becomes clear that STEAMscapers is not simply a supplementary activity to enrich classroom instruction. Instead, it has been designed as a complete teaching scenario with clear structure and purpose. Each step of the design ensures that the escape room is not an isolated activity but a pedagogically integrated learning environment.

Throughout the process, students are encouraged to explore ideas on their own by working through puzzles, following the storyline and dealing with everyday problem situations. An important aspect of the scenario is that it does not require additional teaching for students to grasp key concepts because the digital resources themselves offer enough support and guidance.

Using a narrative framework with tasks grounded in real-life problem solving, the scenario highlights the relevance of the content and increases student engagement. At the same time, it helps them develop essential skills such as critical thinking, teamwork and effective problem-solving. In this way, STEAMscapers merges conceptual understanding and hands-on learning.

To conclude, our scenario demonstrates how digital escape rooms can serve as comprehensive learning experiences, seamlessly aligned with curriculum goals.

IV. RESULTS

The sample consisted of 40 participants. Of these, 30 were female (75%) and 10 were male (25%). Among the respondents, 16 held a degree from a department of education, 35 held a postgraduate degree in e-learning, 4 had a second undergraduate degree and 1 participant held a doctoral degree.

Table III. Descriptive Statistics of STEAMscapers Effectiveness Dimensions

	Minimum	Maximum	Mean	Std. Deviation
Learning Outcomes	2.33	5.00	4.4750	.63554
Course Introduction and Learning Activities	3.40	5.00	4.5150	.47477
Assessment and Measurement	3.50	5.00	4.6875	.41890
Interaction and Feedback	3.00	5.00	4.4083	.54688
Content Quality and Interactivity	4.00	5.00	4.7800	.30984
Course Organization	2.00	5.00	4.5000	.61237

As shown in Table III, the results of the descriptive analysis suggested that STEAMscapers was perceived as highly effective across all evaluated domains. All dimensions scored above 4.40 on the Likert scale, with minimal variance. The Content Quality and Interactivity dimension received the highest average score (M=4.78), while the Interaction and Feedback dimension received the lowest average score (M=4.40).

The lower mean score for Interaction and Feedback may be a result of the structure of the pilot implementation of STEAMscapers. The participants interacted with the digital environment individually and asynchronously. This process did not include and therefore, was not supportive of collaborative group activities. In addition, there were no synchronous videoconferencing sessions, which would have allowed the instructor to provide direct feedback or comments related to participants' performance.

The Learning Outcomes dimension received an average score of 4.47. Most respondents reported that objectives were stated clearly and the activities effectively supported the attainment of objectives.

The Introduction and Learning Activities dimension received a mean score of 4.51, while Assessment and Measurement received a mean score of 4.68. Most participants agreed that the evaluation tasks were closely aligned with the learning content and provided an extensive number of opportunities to monitor their progress.

Content Quality and Interactivity had the highest mean score (M=4.780). Nearly all participants agreed that the information provided was comprehensive in all aspects and that it was fun and easy to understand through the use of the various teaching aids. Furthermore, participants also stated that the use of such tools had a positive impact on their learning and made the online courses more enjoyable.

As shown in Table IV, the overall mean score across all questionnaire items were calculated at 4.5682. So, the sample overall evaluated STEAMscapers as a highly effective learning experience for sixth-grade students.

Table IV. Average value of STEAMscapers' effectiveness

	N	Minimum	Maximum	Mean	Std. Deviation
Average Mean	40	3.64	5.00	4.5682	.36610

In addition, a non-parametric Friedman test was conducted to assess differences among the six effectiveness dimensions of STEAMscapers (Table V). The analysis indicated a Chi-square value of 28.12, which was statistically significant ($p < 0.001$).

Table V. Differences among dimensions (Friedman test)

N	40
Chi-Square	28.122
df	5
Asymp. Sig.	<.001

To identify the dimension that demonstrated a statistically significant difference compared to the others, the Wilcoxon Signed Ranks Test was used.

Table VI. Wilcoxon Signed Ranks Test

Pairwise Comparison	Z	p (2-tailed)
Course Introduction – Learning Outcomes	-0.529	.597
Assessment and Measurement – Learning Outcomes	-2.083	.037
Interaction and Feedback – Learning Outcomes	-0.826	.409
Content Quality and Interactivity – Learning Outcomes	-3.555	< .001
Course Organization – Learning Outcomes	-0.171	.864
Assessment and Measurement – Course Introduction	-2.005	.045
Interaction and Feedback – Course Introduction	-1.485	.138
Content Quality and Interactivity – Course Introduction	-3.733	< .001
Course Organization – Course Introduction	-0.082	.934
Interaction and Feedback – Assessment and Measurement	-3.099	.002
Content Quality and Interactivity – Assessment and Measurement	-1.614	.107
Course Organization – Assessment and Measurement	-1.585	.113
Content Quality and Interactivity – Interaction and Feedback	-3.441	< .001
Course Organization – Interaction and Feedback	-1.217	.224
Course Organization – Content Quality and Interactivity	-3.113	.002

As presented in Table VI, Wilcoxon signed-rank tests with Bonferroni correction (adjusted α=.0033) revealed that Content Quality and Interactivity were rated significantly higher than Learning Outcomes ($p<0.001$), Course Introduction and Learning Activities ($p<0.001$), Interaction and Feedback ($p<0.001$) and Course Organization ($p=0.002$). Additionally, Assessment and Measurement received significantly higher ratings than Interaction and Feedback ($p= 0.002$). Overall, these results highlight participants' strong appreciation for engaging and interactive content, while also pointing out weaker perceptions of interaction and feedback mechanisms.

As shown in Table VII, a Mann–Whitney U test was conducted to examine potential gender differences across the six quality dimensions of STEAMscapers.

Table VII. Gender differences (Mann–Whitney U test)

	Learning Outcomes	Course Introduction and Learning Activities	Assessment and Measurement	Interaction and Feedback	Content Quality and Interactivity	Course Organization
Mann-Whitney U	147.500	108.500	147.000	120.000	109.000	141.500
Wilcoxon W	612.500	163.500	612.000	175.000	164.000	196.500
Z	-.082	-1.319	-.105	-.962	-1.409	-.275
Asymp. Sig. (2-tailed)	.935	.187	.916	.336	.159	.784
Exact Sig.	.939b	.198b	.939b	.363b	.209b	.794b

a. Grouping Variable: Gender
b. Not corrected for ties.

Results indicated no statistically significant differences between male and female participants in learning outcomes ($U= 147.5$, $p= .935$), course introduction and learning activities ($U= 108.5$, $p= .187$), assessment and measurement ($U= 147.0$, $p= .916$), interaction and feedback ($U= 120.0$, $p= .336$), content quality and interactivity ($U= 109.0$, $p= .159$) or course organization ($U=141.5$, $p =.784$). These findings suggest that both genders perceived the platform's effectiveness similarly.

To further explore the interrelationships among the evaluated effectiveness dimensions, a Spearman correlation analysis was conducted. The results are shown in Table VIII, along with an interpretation of the key correlations.

As portrayed in Table VIII, Spearman correlation analysis indicated strong positive associations among the six effectiveness dimensions of STEAMscapers. Learning Outcomes were highly correlated with Course Introduction and Activities ($\rho = .662$, $p < .001$) and Content Quality and Interactivity ($\rho = .590$, $p < .001$). Assessment and Measurement were strongly associated with Content Quality and Interactivity ($\rho = .603$, $p < .001$). Interaction and Feedback were positively related with weaker correlations to all dimensions (ρ ranging from 0.333 to 0.562). Overall, the results indicate that participants who perceived the content as engaging and well-designed were also more likely to report clearer learning outcomes, stronger course structure and more effective assessment processes. In contrast, perceptions of interaction and feedback were less consistently aligned.

Table VIII. Correlation analysis (Spearman's rho)

		Course Introduction and Learning Activities	Assessment and Measurement	Interaction and Feedback	Content Quality and Interactivity	Course Organization
Learning Outcomes	Correlation Coefficient	.662**	.540**	.377*	.590**	.521**
	Sig. (2-tailed)	<.001	<.001	.016	<.001	<.001
	N	40	40	40	40	40
Course Introduction and Learning Activities	Correlation Coefficient		.420**	.562**	.645**	.550**
	Sig. (2-tailed)		.007	<.001	<.001	<.001
	N		40	40	40	40
Assessment and Measurement	Correlation Coefficient			.376*	.603**	.488**
	Sig. (2-tailed)			.017	<.001	.001
	N			40	40	40
Interaction and Feedback	Correlation Coefficient				.376*	.333*
	Sig. (2-tailed)				.017	.036
	N				40	40
Content Quality and Interactivity	Correlation Coefficient					.485**
	Sig. (2-tailed)					.002
	N					40

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

V. CONCLUSION & CHALLENGES

This study demonstrated that STEAMscapers provides an effective and meaningful learning experience. Participants rated the quality of content, interactivity and alignment of assessments with learning objectives. Statistical analysis supports the finding that all three of these variables were highly correlated with achieving learning outcomes as well as the overall structure of each course. In addition, although participants rated the interactivity and feedback lower than the other areas, this finding can likely be explained by the asynchronous implementation of the pilot. Finally, the lack of significant differences related to gender and education level indicates the approach is inclusive and has potential for application across many different populations and experience levels.

Beyond demonstrating the effectiveness of the STEAMscapers, the study also addresses key challenges in modern education. The way the digital escape room is set up, with its puzzles, stories and problems from real life, boosts students to collaborate and solve problems in a critical way. By doing these hands-on activities, students learn to work together and to apply their learning to real-life situations.

The addition of project-based learning also supports the learning process because it shifts students from simply memorizing facts to doing real-world problems that produce actual products. This supports conceptual development as well as metacognitive and self-regulatory skills when students learn how to plan, reflect and improve their work. The way the stories and games are structured in the escape room is also important for motivating and engaging students.

The activities encouraged high levels of interactivity and students continued to engage in the learning experience throughout the session. The assessment components aligned with the scenario and assisted learners in tracking their progress. Multimedia and interactive tools were also integrated into the learning experience, making it as enjoyable and accessible as possible.

In this regard, STEAMscapers can greatly help students prepare for the challenges of the 21st century through the combination of science and technology with creativity and critical thinking in a collaborative environment. This scenario provides a scalable and effective instructional model for primary education and beyond.

However, the absence of existing frameworks that combine STEAM and Project-Based Learning in escape room design posed a significant challenge. Furthermore, selecting the theme was essential in shaping the learning experience. The chosen theme needed to align with students' cognitive levels while remaining relevant to real-life situations. It also had to be feasible within a STEAM-based instructional approach and lead to the development of a tangible project.

Nevertheless, the greatest challenge lay in adapting the instructional scenario to a hybrid digital learning environment. This required carefully selecting appropriate digital tools, aligning learning objectives with the activities and developing high-quality digital content that addressed the needs and capabilities of the student audience.

In summary, STEAMscapers, as presented in this research, provide an innovative instructional scenario incorporating the STEAM along with Project-Based Learning to create a digital escape room for primary educational students—an area of research that has received very limited attention in the current literature. Unlike most existing studies, which see escape rooms as supplementary activities, STEAMscapers is designed as a complete instructional unit carried out over multiple lessons with clearly defined pedagogical phases. Its innovative features include using a narrative structure and real-world problem-solving tasks, as well as an interdisciplinary integration of all STEAM fields.

VI. FUTURE RESEARCH

The current framework was pilot-tested with a sample of e-learning experts. However, it is suggested a further implementation with a sample of actual classroom students be conducted to measure the degree to which learners are engaged in the learning process, assess the effectiveness of the instructional scenario and identify any problems or challenges that could result from implementing this framework. In addition, future studies could include both an experimental and control group and follow appropriate research design. Future studies could measure indicators such as collaboration, engagement and learning outcomes. Doing so would provide a more comprehensive understanding of the educational value and practical application of the escape room framework in real classroom settings.

ACKNOWLEDGMENT

This work has been partly supported by the University of Piraeus Research Center.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors wrote, reviewed and edited the content as needed and verifies that none utilized artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

REFERENCES

[1] N. Foster and M. Piacentini, “Innovating Assessments to Measure and Support Complex Skills”. Paris, France: OECD Publishing, 2023, doi: 10.1787/e5f3e341-en.

[2] L. J. Leifer and M. Steinert, “Dancing with ambiguity: Causality behavior, design thinking, and triple-loop learning,” Information Knowledge Systems Management, vol. 10, no. 1–4, pp. 151–173, 2011, doi: 10.3233/iks-2012-0191.

[3] N. R. Dyrberg and H. T. Holmegaard, “Motivational Patterns in STEM Education: A Self-Determination Perspective on First-Year Courses,” Research in Science and Technological Education, vol. 37, no. 1, pp. 90–109, 2018, doi: 10.1080/02635143.2017.1421529.

[4] Y. Rahmawati, S. F. Ramadhani, and Afrizal, “Developing Students’ Critical Thinking: A STEAM Project for Chemistry Learning,” Universal Journal of Educational Research, vol. 8, no. 1, pp. 72–82, 2020, doi: 10.13189/ujer.2020.080108.

[5] G. Ozkan and U. Umdu Topsakal, “Investigating the effectiveness of STEAM education on students’ conceptual understanding of force and energy topics,” Research in Science & Technological Education, vol. 39, no. 4, pp. 441–460,2021, doi: 10.1080/02635143.2020.1769586.

[6] C. F. Quigley, D. Herro, and F. M. Jamil, “Developing a Conceptual Model of STEAM Teaching Practices,” School Science and Mathematics, vol. 117, no. 1, pp. 1–12, 2017, doi: 10.1111/ssm.12201.

[7] C. C. Chen and P. H. Huang, “The effects of STEAM-based mobile learning on learning achievement and cognitive load,” Interactive Learning Environments, vol. 31, no. 1, pp. 100–116, 2023, doi: 10.1080/10494820.2020.1761838.

[8] K. Swaby and J. V. Ernst, “STEM Education Fiscal Year 2015: An Analysis of Educational Investments and Expectations,” Journal of STEM Teacher Education, vol. 51, no. 1, pp. 17–31, 2016, doi: 10.30707/JSTE51.1Swaby.

[9] S. Xefteris, “Developing STEAM Educational Scenarios in Pedagogical Studies using Robotics: An Undergraduate Course for Elementary School Teachers,” Engineering, Technology & Applied Science Research, vol. 11, no. 4, pp. 7358–7362, 2021, doi: 10.48084/etasr.4249.

[10] J. E. Solanes, S. Montava-Jordà, E. Golf-Laville, V. Colomer-Romero, L. Gracia, & A. Muñoz, “Enhancing STEM Education through Interactive Metaverses: A Case Study and Methodological Framework,” Applied Sciences, vol. 13, no. 19, pp. 1–17, 2023, doi: 10.3390/app131910785.

[11] S. N. Mufida, D. V. Sigit, and R. H. Ristanto, "Integrated project-based e-learning with science, technology, engineering, arts, and mathematics (PjBeL-STEAM): Its effect on science process skills," Biosfer, vol. 13, no. 2, pp. 183–200, 2020, doi: 10.21009/biosferjpb.v13n2.183-200.

[12] I. Rahmania, "Project Based Learning (PjBL) Learning Model with STEM Approach in Natural Science Learning for the 21st Century," Budapest Int. Res. and Critics Inst. (BIRCI-Journal): Humanities and Social Sciences, vol. 4, no. 1, pp. 1161–1167,2021, doi: 10.33258/birci.v4i1.1727.

[13] R. P. Sari, H. Putri Mauliza, and S. Setiawaty, "Implementation of Project Based Learning Model Integrated STEAM Approach to Improve Students' Critical Thinking," J. Educ. in Science, Technology, Mathematics, and Disaster Management, vol. 1, no. 1, pp. 1–13, 2024.

[14] D. V. Sigit, R. H. Ristanto, and S. N. Mufida, "Integration of Project-Based E-Learning with STEAM: An Innovative Solution to Learn Ecological Concept," Int. J. of Instruction, vol. 15, no. 3, pp. 23–40, 2022, doi: 10.29333/iji.2022.1532a.

[15] Z. Zayyinah, E. Erman, Z. A. I. Supardi, E. Hariyono, & B. K. Prahani, "STEAM-Integrated Project Based Learning Models: Alternative to Improve 21st Century Skills," in Proc. 8th SEA-DR & 2nd STEACH Int. Conf., 2021, pp. 251–258, doi: 10.2991/assehr.k.211229.039.

[16] J. Afriana, A. Permanasari, and A. Fitriani, "Penerapan project based learning terintegrasi STEM untuk meningkatkan literasi sains siswa ditinjau dari gender," J. Inovasi Pendidikan IPA, vol. 2, no. 2, pp. 202–212, 2016, doi: 10.21831/jipi.v2i2.8561.

[17] S. Suryanti, M. Nursalim, N. L. Choirunnisa, and I. Yuliana, "STEAM-Project-Based Learning: A Catalyst for Elementary School Students' Scientific Literacy Skills," European Journal of Educational Research, vol. 13, no. 1, pp. 1–14, 2024, doi: 10.12973/eu-jer.13.1.1.

[18] X. Y. Wu, "Unveiling the dynamics of self-regulated learning in project-based learning environments," Heliyon, vol. 10, no. 5, e27335, 2024, doi: 10.1016/j.heliyon.2024.e27335.

[19] M. H. Rohman, P. Marwoto, and S. Priatmoko, "A Study of Sound Materials of Water Hyacinth (Eichhornia Crassipes) as Alternative STEAM Integrated Project-Based Learning Model (PjBL)," Jurnal Penelitian & Pengembangan Pendidikan Fisika, vol. 8, no. 1, pp. 11–22, 2022.

[20] C. Santos et al., "Science education through project-based learning: A case study," Procedia Computer Science, vol. 219, pp. 1713–1720, 2023, doi: 10.1016/j.procs.2023.01.465.

[21] S. Han and K. Bhattacharya, "Constructionism, learning by design, and project based learning," in M. Orey (Ed.), Emerging Perspectives on Learning, Teaching, and Technology, University of Georgia, 2001, pp. 1–18.

[22] O. Borrás-Gené, R. M. Díez, and A. Macías-Guillén, "Digital Educational Escape Room Analysis Using Learning Styles," Information, vol. 13, no. 11, pp. 522–538, 2022, doi: 10.3390/info13110522.

[23] H. Manojlovic, "Escape room as a teaching method," Opus et Educatio, vol. 9, no. 2, pp. 178–188, 2022, doi: 10.3311/ope.504.

[24] H. M. Huang and S. S. Liaw, "An analysis of learners' intentions toward virtual reality learning based on constructivist and technology acceptance approaches," International Review of Research in Open and Distributed Learning, vol. 19, no. 1, pp. 91–115, 2018, doi: 10.19173/irrodl.v19i1.2503.

[25] J. M. Padilla Piernas, M. C. Parra Meroño, and M. D. P. Flores Asenjo, "Virtual Escape Rooms: A gamification tool to enhance motivation in distance education," RIED-Revista Iberoamericana de Educación a Distancia, vol. 27, no. 1, pp. 61–85, 2024, doi: 10.5944/ried.27.1.37685.

[26] L. Huraj, R. Hrmo, and M. Sejutová Hudáková, "The Impact of a Digital Escape Room Focused On HTML and Computer Networks on Vocational High School Students," Education Sciences, vol. 12, no. 10, pp. 682–689, 2022, doi: 10.3390/educsci12100682.

[27] R. Duggins, "Innovation and problem solving teaching case: The breakout box–a desktop escape room," Journal of Organizational Psychology, vol. 19, no. 4, pp. 73–77, 2019, doi: 10.33423/jop.v19i4.2294.

[28] A. Makri, D. Vlachopoulos, and R. A. Martina, "Digital escape rooms as innovative pedagogical tools in education: A systematic literature review," Sustainability, vol. 13, no. 8, p. 1-29, 2021, doi: 10.3390/su13084587.

[29] P. Fotaris and T. Mastoras, "Escape Rooms for Learning: A Systematic Review," in Proc. 13th Int. Conf. Game Based Learning (ECGBL 2019), Odense, 2019, pp. 235–243, doi: 10.34190/GBL.19.179.

[30] A. Veldkamp, L. Van De Grint, M. C. P. J. Knippels, and W. R. Van Joolingen, "Escape education: A systematic review on escape rooms in education," Educational Research Review, vol. 31, 2020, pp. 1-18, doi: 10.1016/j.edurev.2020.100364.

[31] A. Manzano-León et al., "Escape Rooms as a Learning Strategy for Special Education Master's Degree Students," International Journal of Environmental Research and Public Health, vol. 18, no. 14, pp. 1–13, 2021, doi: 10.3390/ijerph18147304.

[32] Z. Karageorgiou, P. Fotaris, and I. Mavrommati, "Escape rooms for STEAM education: Comparing design phases," in Proc. 14th European Conf. Game Based Learning (ECGBL 2020), Brighton, 2020, pp. 287–294.

[33] K. H. Tseng, C. C. Chang, S. J. Lou, and W. P. Chen, "Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment," International Journal of Technology and Design Education, vol. 23, no. 1, pp. 87–102, 2013, doi: 10.1007/s10798-011-9160-x.

[34] L. H. Taraldsen, F. O. Haara, M. S. Lysne, P. R. Jensen, & E. S. Jenssen, "A review on use of escape rooms in education – touching the void," Education Inquiry, vol.

13, no. 2, pp. 169–184, 2022, doi: 10.1080/20004508.2020.1860284.

[35] B. Gancevska and S. Ramanauskaitė, "Taxonomy of E-Course Quality Metrics and Automated Evaluation Possibilities," 2024 IEEE Open Conference of Electrical, Electronic and Information Sciences (eStream), Vilnius, Lithuania, 2024, pp. 1-6, doi: 10.1109/eStream61684.2024.10542575.

[36] D. Laboy-Rush, "Integrating STEM Education through Project-Based Learning," Learning.com, pp. 1–12, 2012, [Online]. https://www.scribd.com/document/48133727/Integrating-STEM-Education-through-Project-Based-Learning (Accessed Date: February 3, 2025).

[37] Adriyawati, E. Utomo, Y. Rahmawati, and A. Mardiah, "STEAM-project-based learning integration to improve elementary school students' scientific literacy on alternative energy learning," Universal Journal of Educational Research, vol. 8, no. 5, pp. 1863–1873, 2020, doi: 10.13189/ujer.2020.080523.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Michael Bouskos designed and implemented the escape room for elementary school students.
- Foteini Paraskeva served as the scientific lead for the research design.

Sources of funding for research presented in a scientific article or scientific article itself

No funding was received for conducting this study.

Conflicts of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.