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DIGITAL ESCAPE ROOMS TO DEVELOP COMPUTATIONAL THINKING: LEARNING ANALYTICS IN SCIENCE CLUB

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ABSTRACT

Aim/Purpose	The objective of this study was to identify the elements of learning analytics and the characteristics that digital escape rooms should have in order to promote the development of computational thinking in challenging environments.
Background	In the present and future of education, developing computational thinking is strategic for the digital age, serving as a bridge between technology and problem-solving. There is an opportunity to look for new ways to promote computational thinking because people have difficulty abstracting real problems and applying decomposition methods, design patterns, and algorithmic thinking in various complex contexts.
Methodology	The ADDIE framework (analysis, design, development, implementation, and evaluation) was applied to develop an escape room with learning analytics and challenges focused on Sustainable Development Goal 7 (Affordable and Clean Energy). The application was carried out with 119 participants from the science club.

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Contribution	This research provides practical specifications for developing digital escape rooms that implement learning analytics. This study is of great value to academics, developers, and decision-makers interested in developing training activities that promote high-level skills for dealing with complexity.
Findings	The physical and logical models created can guide the implementation of requirements and database creation when developing educational digital escape rooms. A timeline, event history analysis, and a method examining the sequence of discrete states can measure computational thinking development and identify other high-level competencies in educational digital escape rooms. Essential features of web-based educational digital escape rooms include an adaptive design for optimal visualization and interaction, accessibility across a variety of devices, easy navigation, and challenges that include puzzles and time-limited problems.
Recommendations for Practitioners	Suggestions for practitioners who want to enhance high-level competencies include: (a) employ challenge-based strategies like an educational digital escape room, (b) gradually increase the difficulty of challenges to monitor competency development, (c) control the time students spend solving puzzles, and (d) continuously evaluate the strengths and weaknesses of the educational digital escape room for ongoing improvement.
Recommendations for Researchers	Researchers who want to develop high-level competencies through educational digital escape rooms should consider timelines, event history analysis, and a method that scrutinizes the students' sequence of discrete states while answering questions, which allows effective progress tracking.
Impact on Society	This study contributes to open education by creating quality open educational resources for the development of high-level competencies.
Future Research	Future research could expand the analysis to include qualitative data, population samples from clubs in other countries, and educational digital escape rooms targeting other sustainable development goals.
Keywords	complex thinking, educational innovation, higher education, computational thinking, escape rooms, sustainable development objectives

INTRODUCTION

Computational thinking (CT) is considered a higher-level competency, comprising four abilities: abstraction, decomposition, pattern recognition, and algorithmic thinking. The primary role of CT is problem-solving. It has been the focus of several research projects. Jou et al. (2023) used the creative problem-solving method to improve the CT of engineering students and found that this method promotes motor skills, but they did not explore the deep interaction processes. Abdul et al. (2022) demonstrated that augmented reality can improve CT, visualization, and geometry skills. Nevertheless, the method did not incorporate an analysis of the data derived from user interactions with the application. CT increases students' interest, satisfaction, flow state, acceptance of technology, and digital self-efficacy (Hooshyar et al., 2021). Liao et al. (2022) concluded that CT enhances the thinking and logic competencies for problem solving and aids the student in interacting across domains. They used quantitative surveys for the study, but this evaluated only perceptions. It is important to develop CT to look for appropriate strategies like educational digital escape rooms (EDER).

EDERs are a valuable opportunity to develop CT and foster other competencies. EDERs have proven to be an effective and engaging way to teach 21st century skills. For Lopez-Pernas et al.

(2019a), the utilization of gamified environments has been demonstrated to promote teamwork, leadership, creative thinking, and communication among students. Through a literature review, Taraldsen et al. (2022) determined that most studies related to EDERs have focused on their implementation, use, setting, curriculum, 21st-century skills, and motivation. The study also highlights the need for structured and transparent data collection and analysis research methods. EDER is suitable for processing, testing, and formative assessing scientific knowledge and skills because the students think hard using multiple thinking skills (Veldkamp et al., 2021). They allow the incorporation of new assessment tools for information gathering, leading to the adoption of new ways of understanding and developing distance learning (Makri et al., 2021). They can generate positive feelings about the acquisition of knowledge and skills (Sánchez-Ruiz et al., 2022). This research shows the development of an EDER implemented in the Science Clubs program, highlighting the use of learning analytics for monitoring the performance of participants.

Science Clubs are an opportunity to implement EDERs properly. Science Clubs offer free extracurricular Science, Technology, Engineering, and Mathematics (STEM) training to high school students and university undergraduates with scientific vocations (Clubes de Ciencia México, 2023). They are suitable environments for collaborative scientific activities with peers and professionals from different areas (Martín-García et al., 2024). Some Science Clubs have focused on activities that develop CT and complex thinking skills. For example, they have used programming to analyze hyperspectral images, software projects to exemplify the augmentation of human senses, and activities where participants do programming in Python and other computer languages (Science Clubs International, 2023). However, before this research, EDERs were not used in Science Clubs International programs.

In this research, an EDER focused on the challenges related to Sustainable Development Goal (SDG) 7, Affordable and Clean Energy, was developed. SDG 7 seeks to ensure universal access to clean energy. There are 17 SDGs; they constitute a United Nations action plan to end poverty, fight inequality, and address climate change by 2030 (United Nations, 2025). The member states of the United Nations are responsible for carrying out actions to achieve the 17 SDGs. Other EDERs have addressed issues related to SDG 7, but none have used CT as a high-level competency. Ouariachi and Wim (2020) suggest that EREDs in climate change education can facilitate experiential learning, problem-solving, critical thinking skills, and a sense of collaboration. Reinkemeyer et al. (2022) argue that more research is needed to determine the effectiveness of EREDs. This research addresses this gap and aims to determine how EDERs in Science Clubs Mexico 2023 can assess participants' CT development, using learning analytics for monitoring their learning.

This research was part of the E4C&CT Ecosystem for Scaling Up Computational Thinking and Reasoning for Complexity, a project coordinated by the Scaling Complex Thinking for All Research Group (2022), which seeks to create a digital ecosystem for developing CT skills using personalized learning tools. For this purpose, an EDER entitled Save the Planet was developed. The research question was: How does the implementation of learning analytics in EDER, focused on SDG-related issues, support the development of CT in Science Club programs? The sub-question was: What should be the characteristics of escape rooms aiming to develop CT competencies to address SDG-related issues?

This article is structured as follows. First, a literature review of research on EDER, CT, and complex thinking in science clubs is discussed. Then, the materials and methods, including ethical factors, are presented, followed by the results. Finally, the discussion and conclusions are offered, including implications for practice, research, and possible future studies.

LITERATURE REVIEW

Educational escape rooms

An EDER is an engaging and innovative educational tool designed to present challenges students must solve, fostering problem-solving skills across various domains. Despite EDERs' recent introduction, they develop critical competencies adaptable to online, in-person, or hybrid learning environments. These competencies encompass communication, critical and analytical thinking, and teamwork through integrating information and communication technologies (ICT) with the elements, structures, and rules of games in educational contexts, offering the advantage of low-risk implementation (Bellés-Calvera, 2022; Helbing et al., 2023). Compared to traditional methods, in subjects such as mathematics, EDERs improve performance, motivation, autonomy, and decrease anxiety (Saleh, 2023; Stohlmann, 2023). In STEM education, EDERs have diminished the perceived complexities associated with these disciplines (Sidekerskienė & Damaševičius, 2023). According to López-Pernas et al. (2022), these environments led to significant improvements in student engagement and learning outcomes, particularly in programming courses. Dunne (2023) supports this, emphasizing their role in fostering active engagement. The iterative process of designing, piloting, evaluating, and redesigning is crucial for maximizing their educational value (Morrell et al., 2020). Their flexibility facilitates meeting diverse educational demands, exemplified by their application for enhancing CT skills.

The application of EDERs in engineering has yielded positive results; however, it remains an area ripe for further study. Lopez-Pernas et al. (2019b) implemented EDERs in teaching programming in higher education and found that students preferred these resources over traditional laboratory sessions. Another notable study by Borrego et al. (2017) showed positive results in improving learning and increasing motivation in Computer Networks and Information and Security subjects. EDERs have been used in remote Software Engineering Fundamentals courses, demonstrating their effectiveness and the interest they generate among students (Gordillo et al., 2019). This underscores the applicability of EDERs in engineering, a challenging STEM area.

Computational and complex thinking

Research on CT emphasizes its role in problem-solving, with a significant portion leveraging technology to enhance learning outcomes. Deng et al. (2023) devised a framework that integrates suitable technological environments, content design, and methodological applications to support the development of CT. Similarly, Liu et al. (2023) proposed a model that correlates learning engagement with CT, deducing that both emotional and cognitive engagement have a significant impact on the development of CT in smart classroom settings. Furthermore, Boom et al. (2022) explored CT as a broad problem-solving skill within computer programming tasks, discovering that applying CT processes improves programming quality. These studies indicate that CT is gaining recognition as an increasingly important competency.

Another high-level competency that is gaining recognition for its usefulness in problem solving is complex thinking. The development of complex thinking allows people to increase their ability to address the problems and challenges of their environment, regardless of the discipline they practice (Medina-Vidal et al., 2023). In science education, complex thinking has gained relevance (Molnár et al., 2024). Various techniques, such as game-based learning, have been used to develop it because there is evidence that it fosters students' resilience, creativity, and motivation (Henderson, 2022). Complex thinking may be able to cope with situations characterized by uncertainty, emergence, and incompleteness of knowledge because it provides a broad systemic approach to address ill-defined, ill-structured, and unpredictable problems (Sigahi et al., 2023). The significance of this competence has prompted the exploration of various methodologies for its development

Science club programs

Activities within non-formal programs, such as science clubs, can foster the development of high-level competencies such as complex thinking. This form of thinking enables individuals to solve problems by integrating innovative, scientific, critical, and systemic skills (Cruz-Sandoval et al., 2023). Complex thinking allows for managing uncertainty based on what has been learned and studied (Baena-Rojas et al., 2022). In addition, it enables solutions to complex social problems to be proposed in different environments (Ramírez-Montoya et al., 2021). Science clubs offer an environment where students can learn with a deep understanding and strengthen collaboration, teamwork, leadership, and communication skills (Magaji et al., 2022; Sewry et al., 2023). Science clubs can disseminate knowledge to a broader audience, mitigating inequalities.

Designing inclusive activities to narrow knowledge gaps is crucial to achieve this. Buenestado-Fernández et al. (2023) noted that STEM majors in a science club attributed inequalities in science fields to biological and psychological factors. These clubs offer platforms for exploring scientific concepts, conducting experiments, and discussing similar interests with peers. Participation in science clubs develops critical thinking skills and scientific knowledge and fosters a passion for STEM fields (Clubes de Ciencia México, 2023). Science clubs are a complementary pathway for engaging students in interactive learning outside the traditional classroom. The extracurricular science clubs under discussion have involved communities from two countries, the United States and Mexico, with high-impact formative trajectory work over the last decade.

MATERIALS AND METHODS

The E4C&CT Ecosystem for Scaling Up Computational Thinking and Reasoning for Complexity project involved developing a dedicated web platform to facilitate user interaction with EDER activities. The EDER Save the Planet was developed using the ADDIE framework, which is practically synonymous with the generic instructional system development process that contemplates the phases of analysis, design, development, implementation, and evaluation (Molenda, 2003). ADDIE is a framework to which various instructional design models adhere (Allen, 2017). In this case, it was selected due to its simplicity and flexibility for iterations between phases, and not exactly a linear structure.

ANALYSIS

In the analysis phase, the Canvas model, designed by Molina Espinosa et al. (n.d.), was used. This model considers: (a) learning objective, (b) competence, (c) SGD, (d) strategy, (e) components and points of interest, (f) interaction, (g) potential risks, (h) evidence of learning, (i) evaluation instrument to be used, and (j) lifelong learning.

The considerations of Doherty et al. (2023) were also taken into account. The objectives and the topic were identified, and the roles to develop the ERED were two software developers, an expert in instructional design, a CT expert, and an expert in serious games, who were part of the E4C&CT Ecosystem for Scaling Up Computational Thinking and Reasoning for Complexity project. The selection of the host where the EDER was hosted was the responsibility of the software developers, while the CT expert and the expert in serious games carried out the design of the puzzles and problems. Analytical techniques and questionnaires were used for the evaluation. The development process is detailed below.

DESIGN

Designed with a responsive layout, the platform ensures optimal viewing and interaction across multiple devices, including PCs, tablets, and smartphones, thus providing users with diverse technological accessibility.

Upon entering the platform, participants are greeted with the home page interface shown in Figure 1. This initial screen is designed to be intuitive and easy to use, guiding users to begin their escape room experience. The content and initiation of the escape room's educational challenges are activated through a highly visible "Go" button. This design element is crucial to streamlining access to the escape room activities, ensuring that participants can easily navigate to the engaging and educational content prepared for them.

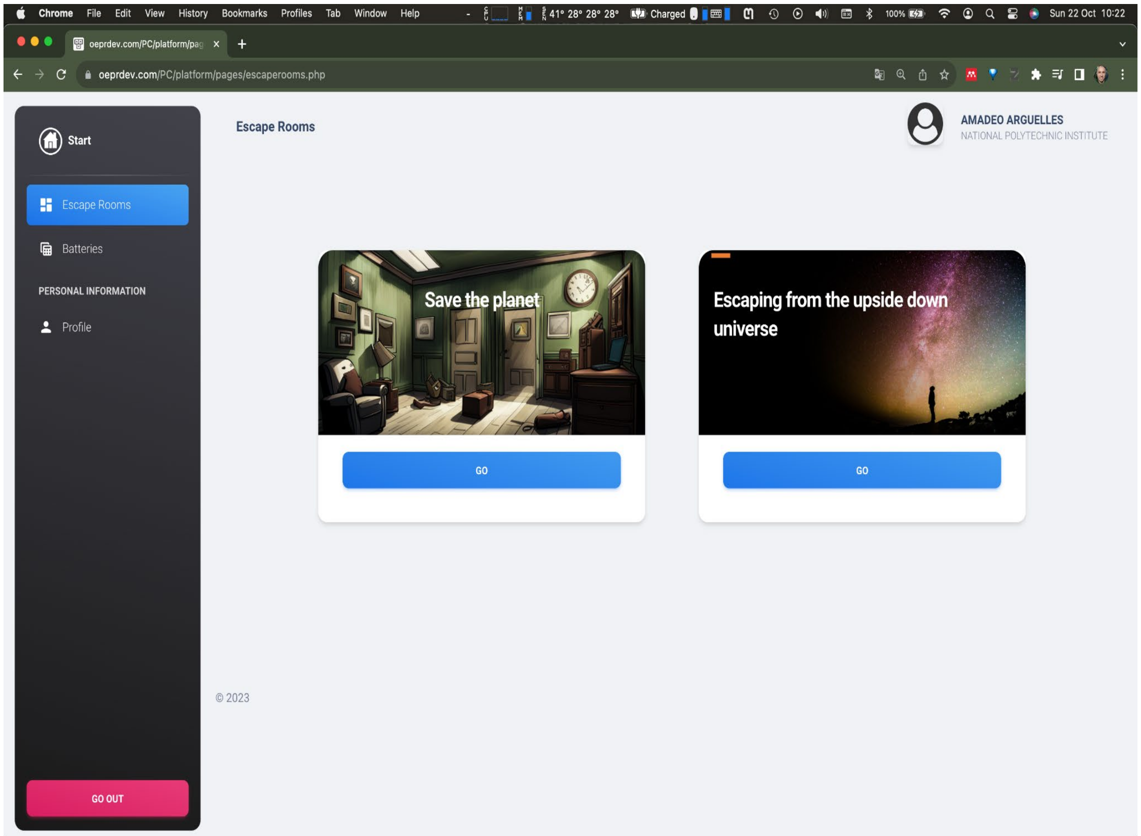

Figure 1. Escape rooms interface

Each button in Figure 1 contains the fundamental elements of each escape room: a series of challenges involving puzzles and problems that must be solved within a set time limit. The four sub-competencies of CT, woven into each activity, occupy a central place in the EDERs. This strategic design choice aims to immerse students in a captivating and educational context, with puzzles and tasks meticulously tailored to the learning objectives. By engaging in thematic issues associated with the SDGs, students can deploy their knowledge and skills to foster critical thinking and problem-solving, which are vital elements of complex thinking.

DEVELOPMENT

Figure 2 illustrates the educational platform's physical layout and infrastructure of the escape rooms. This representation is crucial for understanding the platform's tangible aspects, including hardware requirements, spatial organization, and user interaction mechanisms. The physical setup plays a pivotal role in facilitating an immersive and engaging user experience, which is essential for the effective delivery of educational content.

The implications of this physical representation for both practice and research are substantial. For practitioners, understanding the physical requirements and layout can inform the development of similar educational platforms, ensuring they are accessible and user-friendly. Physical representation also offers insights into optimizing physical spaces to enhance learning outcomes. For researchers, Figure 2 provides a foundation for studying the impact of physical environments on learning efficiency, engagement levels, and user satisfaction in digital learning contexts.

The insights gained from the physical representation of the platform could lead to innovations in educational technology design. Educators and technologists can develop more refined approaches to creating educational spaces that support interactive and immersive learning experiences by evaluating the effectiveness of different physical setups.

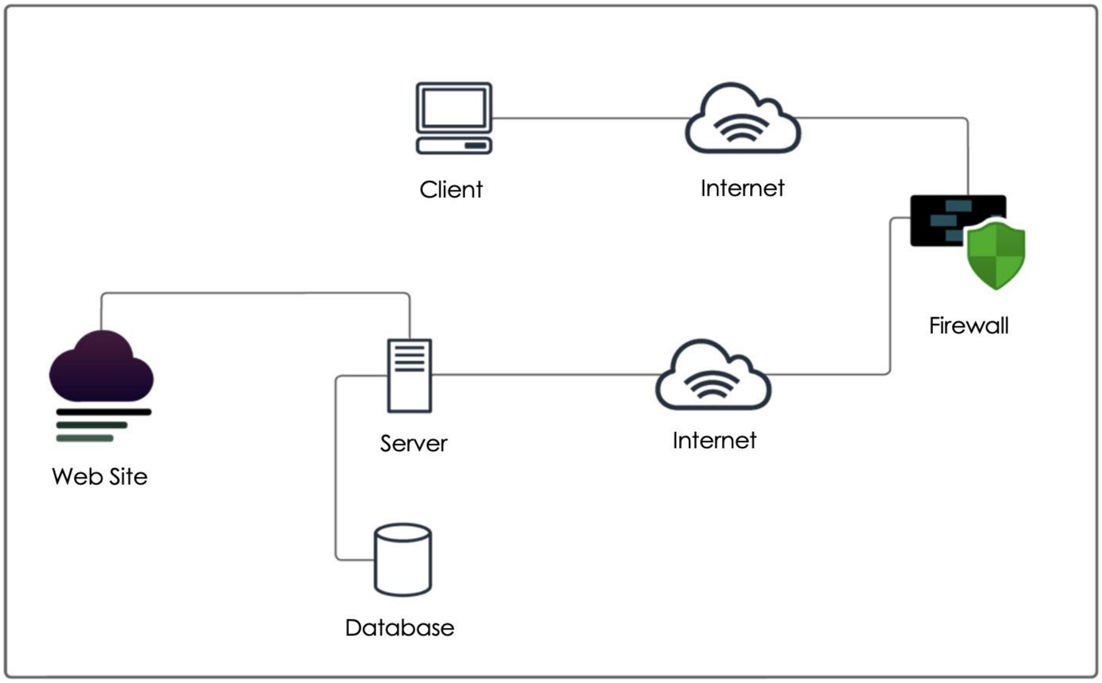

Figure 2. Physical diagram of the platform

Figure 3 presents the logical diagram of the platform, which illustrates the architecture of the database design, including the various fields and records that comprise the system. The fields that store the answers to the questions are identified with the letter "r". This diagram is fundamental to understanding how data is structured, stored, and accessed within the platform, revealing the underlying mechanisms that support user interactions, content delivery, and progress tracking.

The logical structure depicted in Figure 3 has significant implications for the practical application of educational platforms and future research. It provides a model for developing robust, scalable, and efficient digital learning environments. By detailing the database design, Figure 3 enables developers to replicate or enhance this structure in future projects, ensuring data integrity and optimized performance. For researchers, the logic diagram is a critical resource for analyzing the effectiveness of data management strategies in educational settings, which can lead to advances in educational software development.

Future uses of the information in Figure 3 could include refining database architectures for educational platforms and improving their scalability and adaptability. As educational technology evolves, the principles outlined in the logic diagram can serve as the basis for creating more sophisticated, user-centered learning management systems, thus advancing the field of digital education.

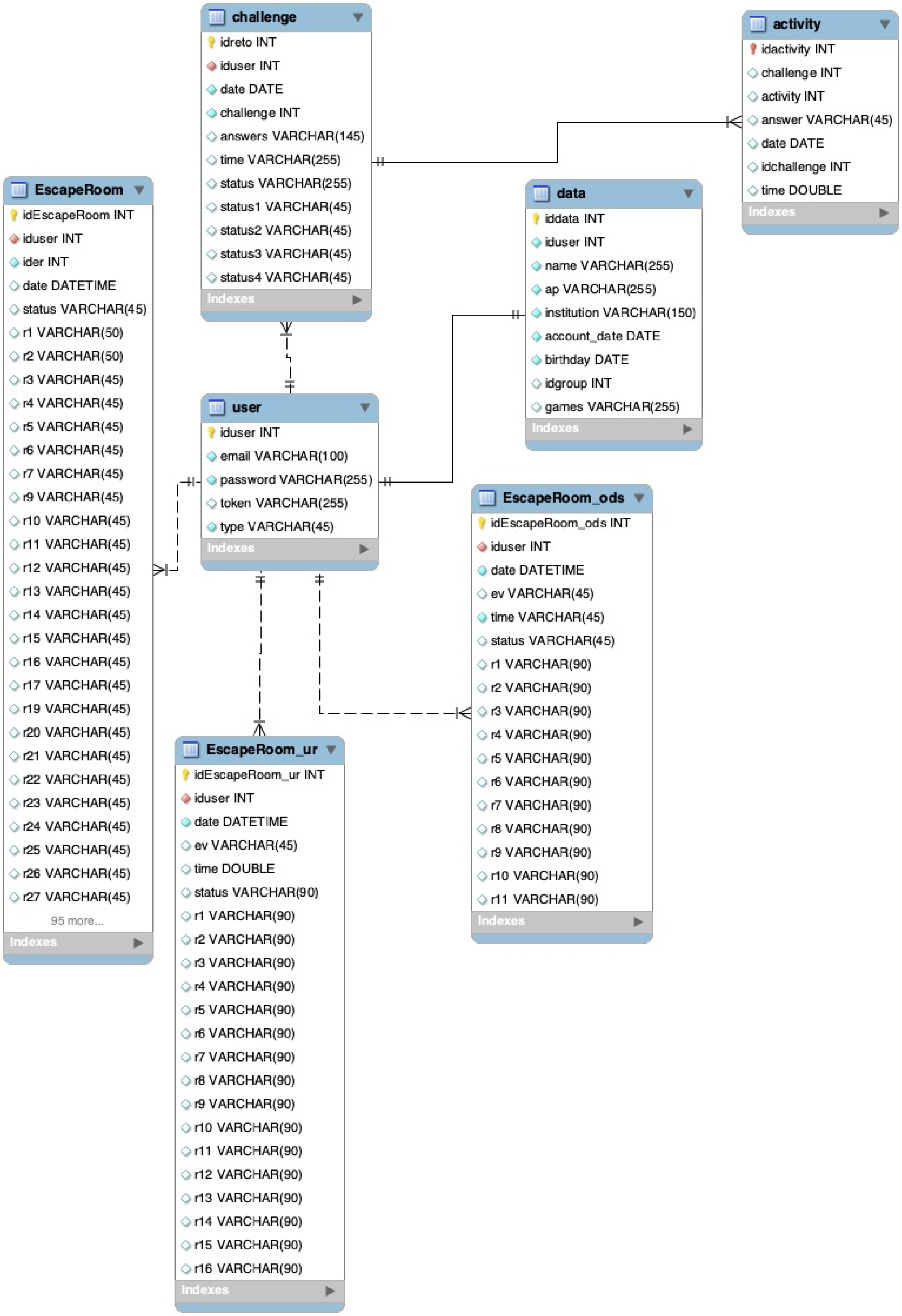

Figure 3. Logical diagram of the platform

IMPLEMENTATION

A total of 119 students from 37 educational institutions in 16 Mexican states: Aguascalientes, Baja California, Chiapas, Chihuahua, Mexico City, Coahuila, Durango, Guadalajara, Hidalgo, Jalisco, Nuevo León, Oaxaca, Puebla, Veracruz, Yucatán, and Zacatecas utilized the platform, showing its broad reach and applicability. A total of 36 men, 58 women, and 25 individuals who opted for anonymous data were included in the study. The sampling method was non-probabilistic; for convenience, this sampling was used because the invitation to participate in the research was extended to all attendees of the 2023 edition of Science Clubs in Mexico, which provided an appropriate approach for the researchers (Palinkas et al., 2015).

The answers to the quizzes and problems were stored in four tables of the logical diagram of the platform (Figure 3). Each response was stored in a different record. To resolve the challenges, it was necessary to use the components of CT. All challenges were aligned with the theme related to SDG 7. For learning analytics purposes, the platform that hosted the EDER "Save the Planet" was designed to provide detailed records of each learner's interactions.

Selecting the "Save the Planet" escape room on the platform leads the participants to develop the activity shown in Figure 4. The EDER is structured around four distinct challenges, each exploring a specific aspect of environmental science and policy. "Solar Energy" is the focus of the first challenge, which includes 23 questions to test and enhance participants' knowledge of renewable energy sources. The second challenge addresses "Climate Change" through 26 questions and aims to improve awareness about the causes and impacts of global warming. The third challenge focuses on "Electromobility," with 26 questions exploring electric vehicles' significance in reducing carbon footprints. The final fourth challenge, with 26 questions, examines the "Effects of Temperature Increase," focusing learners on the profound environmental and societal consequences of rising global temperatures.

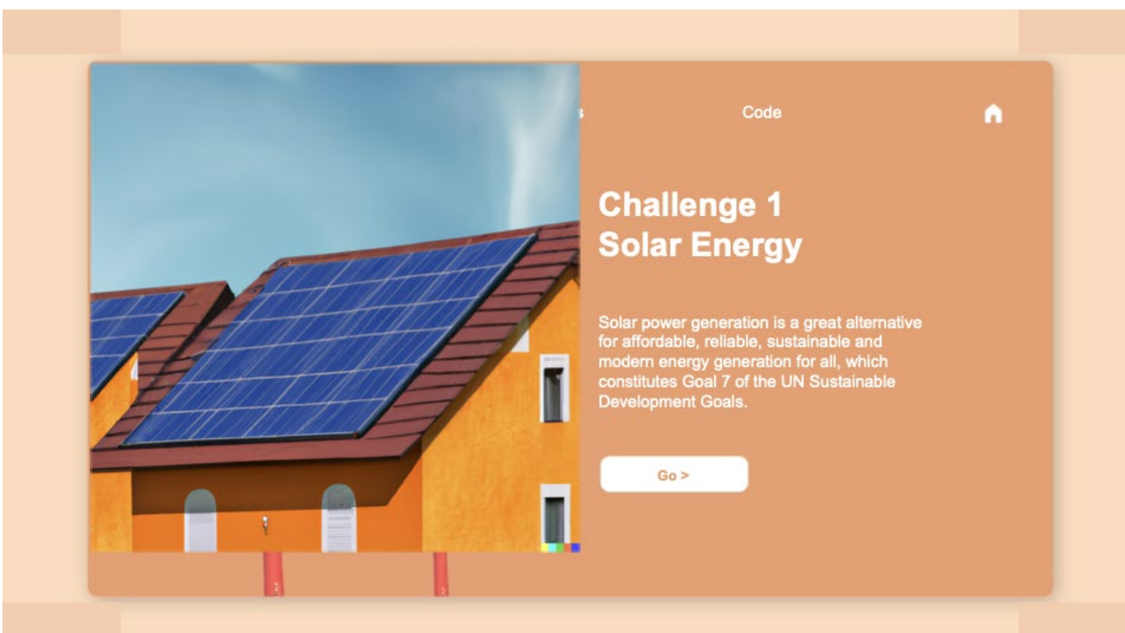

Figure 4. One of the four challenges in the "Save the Planet" escape room

Figure 5 shows an example of one of the activities designed to help students identify their understanding of pattern recognition, decomposition, abstraction, and algorithmic thinking, which are CT competencies. The questions were designed for an expert group in CT. Students earned 1 point for each correctly answered item. In cases of incorrect answers, students could respond again before advancing to the next activity. The evaluation scale allowed scoring from 0 to 10 points. Correctly answering the questions led to the final objective of the escape room: finding the code to save planet Earth.

The data collected through a web platform with the EDER activities and challenges described in the previous section were stored in a database to analyze the degree of CT mastery developed by the students.

Figure 5. Item example in the Save Planet Earth EDER

EVALUATION

For assessing mastery in CT, students from science clubs were invited to participate in the field tests. Activities were organized around four key areas to determine the students' degree of mastery of CT: pattern recognition, decomposition, abstraction, and algorithmic thinking. Figure 6 examines the methods for assessing student performance in science club activities. Initially, the figure highlights tracking students' answer accuracy and response times, which yields a comprehensive picture of their learning efficiency and engagement. Significantly, this analysis distinguishes between correct and incorrect responses, meticulously noting the time dedicated to each question and pinpointing the specific skills impacted by errors. It introduces a dynamic metric: the response effectiveness percentage. This measure, which adjusts in real-time based on a student's overall performance in the challenges, provides a layered insight into their comprehension and skill acquisition. The measurement of time taken by participants to complete the challenges enables the differentiation of their performance. Initially, this allows for the evaluation of quizzes in terms of difficulty, as well as the classification of students and the subsequent design of personalized educational practices.

Concerning the practical implications of this analytical framework, it is clear that the insights garnered are significant. Educators and facilitators equipped with this data are positioned to customize feedback, accurately identify areas of difficulty, and adapt educational content to bridge knowledge gaps. Simultaneously, this detailed analysis acts as a mirror for students, reflecting their learning journey's highs and lows and facilitating a deeper self-awareness regarding their academic strengths and areas needing improvement. The importance of such a data-driven approach is magnified within the research domain. Figure 6 serves as a testament to the power of analytics in enriching our comprehension of educational dynamics and student outcomes.

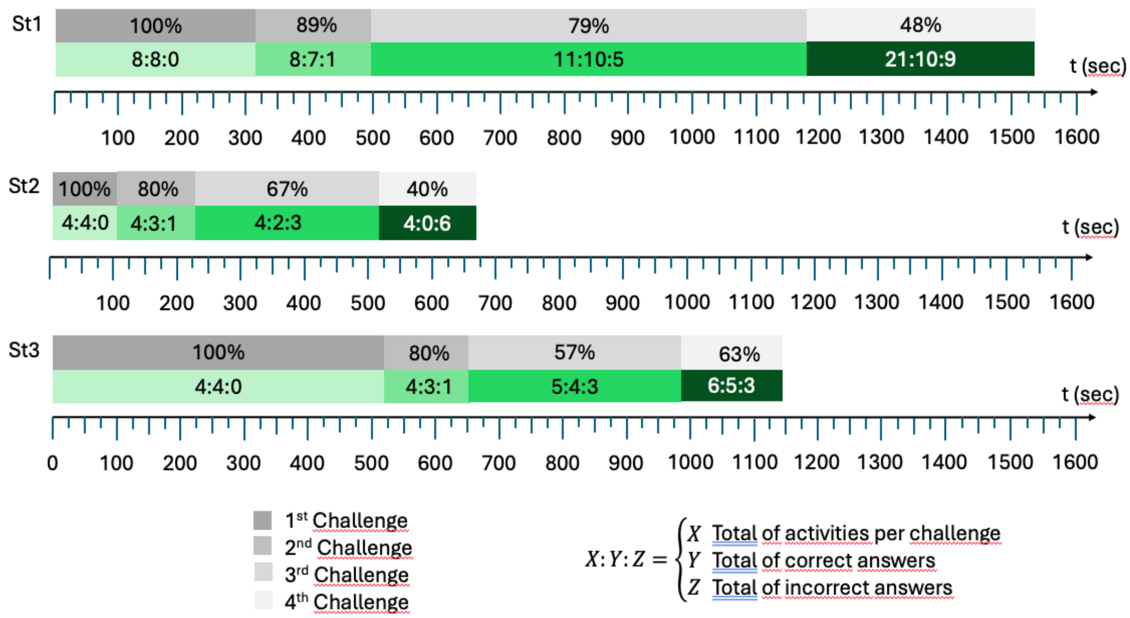

Figure 6. Sample timeline analysis of activity responses of Science Club students

The potential for the methodologies illustrated in Figure 6 to revolutionize personalized learning is immense. With the continuous evolution of educational technologies, integrating sophisticated real-time analytics and adaptive learning frameworks based on comprehensive data analysis is expected to gain momentum. Such advancements promise to transform educational practices, making them more effective and profoundly engaging. They pave the way for creating highly responsive learning environments that are attuned to each learner's individual needs, marking a significant leap forward in the quest to personalize education.

Ethical Factors

This research was approved by the institutional ethics committee of the Tecnológico de Monterrey with approval number: Tecnológico de Monterrey-IFE-2024-001. All participants provided their consent for the use of their data in this research. Participation in the study was voluntary. To ensure data confidentiality, the input records were anonymized in compliance with data privacy regulations.

Results

Table 1 showcases the innovative approach of learning analytics taken in the research to gather data on student interactions within the EDER activities conducted as part of the science club initiative. Leveraging cloud computing and a purpose-built web application, the research team implemented an observation plan designed to capture the nuanced dynamics of student engagement and response patterns. The centerpiece of this data collection effort is the event history analysis, which scrutinizes the sequence of discrete states a student navigates while answering questions. This analysis highlights the students' "episodes" or response durations, framing each moment of engagement as a distinct state of attention.

The implications of such a detailed and technologically advanced data collection method are multifaceted; it equips educators and researchers with a granular view of learning behaviors, enabling them to pinpoint areas where students might struggle or excel. This level of insight is invaluable for tailoring educational content and strategies to meet students' needs more effectively. In the realm of research, Table 1's data serves as a robust foundation for exploring the efficacy of escape room-based learning, providing a consistent and comprehensive dataset for analysis.

Table 1. Example of data collection for each EDER event, showing the details of how one of the students responded

Challenge	Activity	CT sub-competency	Date	Time (sec)	Answer	Evaluation
1	1	Pattern recognition	31/07/2023	21	D	Correct
1	2	Decomposition	31/07/2023	402	B	Correct
1	3	Abstraction	31/07/2023	75	Solar	Correct
1	4	Algorithmic thinking	31/07/2023	22	A	Correct
2	1	Pattern recognition	31/07/2023	17	B	Correct
2	2	Decomposition	31/07/2023	60	C	Correct
2	3	Abstraction	31/07/2023	46	B	Correct
2	4	Algorithmic thinking	31/07/2023	13	B	Incorrect
2	4	Algorithmic thinking	31/07/2023	1	A	Correct
3	2	Decomposition	31/07/2023	114	D	Incorrect
3	1	Pattern recognition	31/07/2023	33	C	Correct
3	2	Decomposition	31/07/2023	10	B	Correct
3	3	Abstraction	31/07/2023	26	C	Incorrect
3	3	Abstraction	31/07/2023	11	E	Correct
3	4	Algorithmic thinking	31/07/2023	85	E	Incorrect
3	4	Algorithmic thinking	31/07/2023	12	B	Incorrect
3	4	Algorithmic thinking	31/07/2023	30	G	Correct
4	1	Pattern recognition	31/07/2023	42	B	Correct
4	2	Decomposition	31/07/2023	12	B	Correct
4	3	Abstraction	31/07/2023	64	E	Incorrect
4	3	Abstraction	31/07/2023	12	C	Correct
4	4	Algorithmic thinking	31/07/2023	24	A	Incorrect
4	4	Algorithmic thinking	31/07/2023	8	E	Incorrect
4	4	Algorithmic thinking	31/07/2023	1	C	Correct
4	4	Algorithmic thinking	31/07/2023	4	C	Correct

The methodologies and data presented in Table 1 hold significant promise for enhancing educational practices and research. The detailed tracking and analysis of student performance during EDER activities open avenues for developing more adaptive and responsive educational technologies. By understanding students' specific states of attention and learning progressions, future educational tools and activities can be designed to optimize learning outcomes, making education more personalized and effective. As such, Table 1 represents a snapshot of student performance and a stepping stone toward the future of interactive and engaged learning.

Analysis of Student Performance in the Escape Room

Figure 6 gives a thorough visual representation of a student's participation in the "Save the Planet" EDER, illustrating the dynamic process of interaction that the web application has recorded. Using event history analysis, Figure 6 tracks the evolution of the student's responses over time, focusing specifically on the transitions between different states of engagement and the rates at which these transitions occur. This analytical approach is adept at uncovering patterns in time-dependent behaviors, making it a powerful tool for assessing the development of CT skills among participants. By meticulously evaluating the duration students take to answer each question, the analysis aims to quantify their proficiency in CT, offering insights into their learning progression and mastery of the subject.

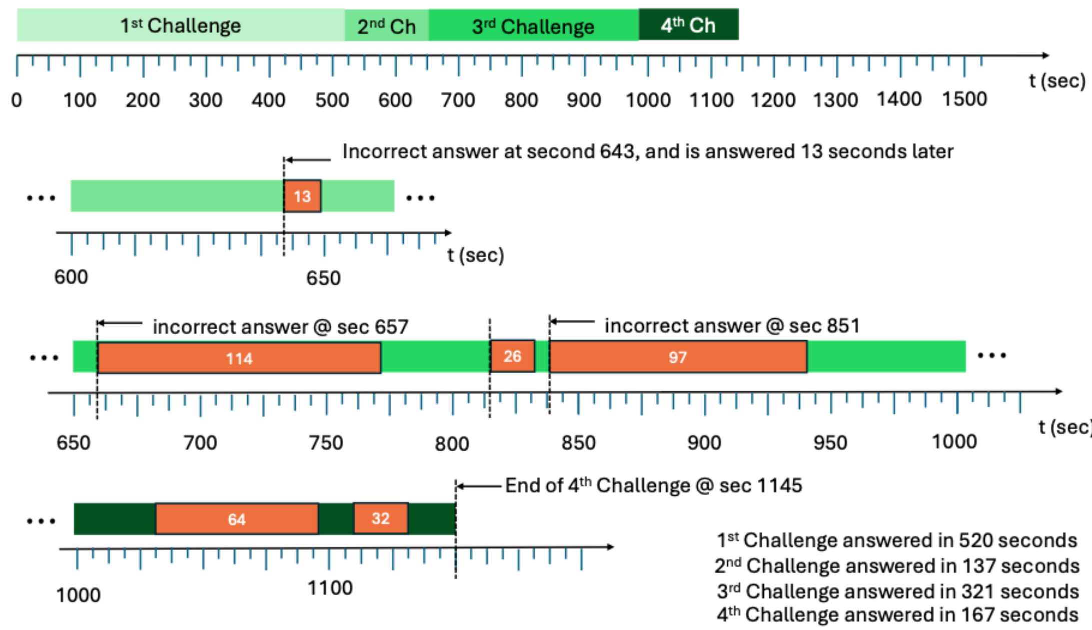

Figure 6. Event history analysis for one of the science club participants in the "Save the Planet" EDER

The implications of Figure 6 for educational practice and research are significant. For practitioners, such detailed analysis provides a deeper understanding of how students interact with learning material, highlighting areas where interventions may be necessary to support skill development. This can lead to designing more effective educational strategies and customizing learning experiences to better meet individual students' needs. For researchers, the application of event history analysis in educational settings opens new avenues for exploring the dynamics of learning processes, particularly in game-based learning environments like escape rooms. This approach enriches understanding of how students develop critical thinking and problem-solving skills and contributes to the broader field of educational technology by offering methodological innovations.

The approaches shown in Figure 6 can improve the efficacy and personalization of learning experiences. With the advancement of educational technologies, educators may customize learning environments to meet the individual learning paths of each student by incorporating advanced data analysis techniques like event history analysis as standard practice. By moving toward more adaptive, data-driven teaching strategies, learning may become more efficient, effective, and tailored to the needs of each student, raising the bar for the quality of education.

Performance Across Different Challenges

Figure 7 charts the progression of participants' performance across different challenges within the EDER, revealing a notable descending trend in success rates as participants advance through the series of challenges. This information was obtained from the answers to the quizzes and problems stored in the EDER logic diagram (Figure 3). The initial challenge sees participants achieving a high success rate, with performance diminishing as they proceed to subsequent challenges, culminating in the lowest performance in Challenge 4. An overall performance rate of 74.19% across the entire escape room experience quantifies this pattern, with individual challenges showing varying degrees of success, from 92.31% in Challenge 1 to 54.01% in Challenge 4.

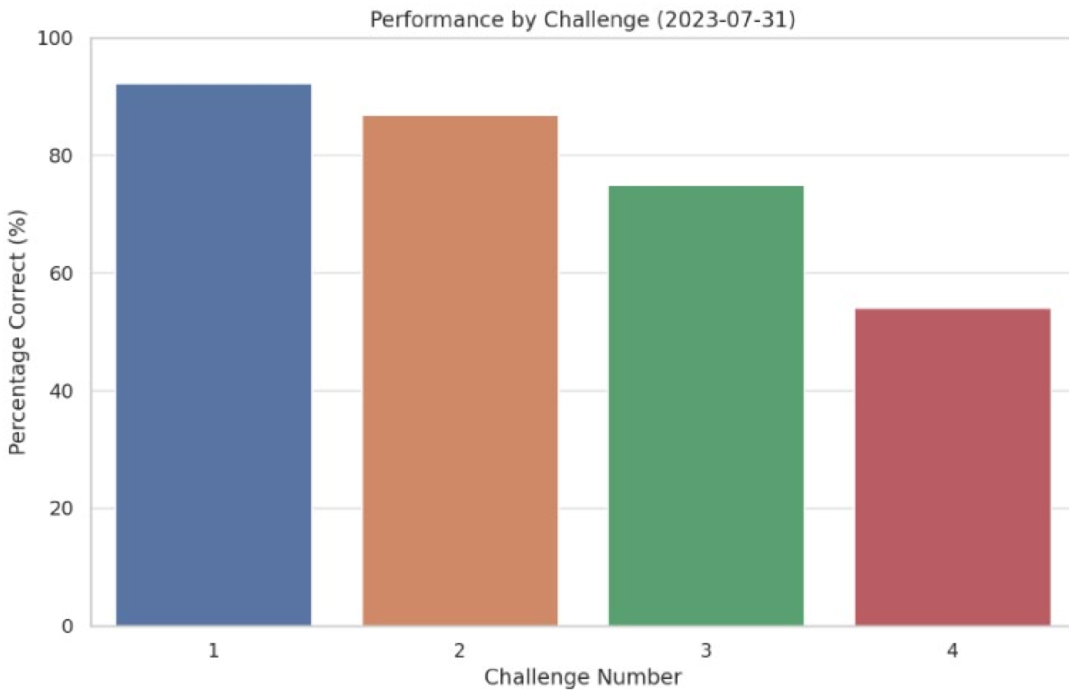

Figure 7. Performance for each challenge: Challenge 1 had 92.31% correct answers; Challenge 2, 86.81%; Challenge 3, 75.00%; and Challenge 4, 54.01%

Figure 7's implications for educational practice and research are manifold. For educational practice, this trend of diminishing performance could signal to educators and curriculum designers the need to recalibrate challenge difficulty or integrate additional support mechanisms in subsequent challenges to better align with participants' skill levels. This trend may also suggest diversifying instructional strategies to maintain or enhance engagement and learning outcomes throughout the EDER experience. For research, the observed performance trend offers fertile ground for investigating the factors contributing to varying difficulty levels and their impact on learning outcomes. This could include exploring the cognitive load associated with each challenge, the alignment of challenge content with participant knowledge, and the effect of increasing difficulty on motivation.

Looking ahead, the insights from Figure 7 could inform the design of future educational escape rooms and similar interactive learning environments. By understanding the relationship between challenge difficulty and participant performance, educators and designers can create more balanced and compelling learning experiences that cater to a wide range of learner abilities. Additionally, this data can contribute to developing adaptive learning technologies that adjust challenge levels in real-time based on participant performance, thereby optimizing learning outcomes and engagement. In this way, the information shown in Figure 7 provides a snapshot of current participant performance trends and serves as a guidepost for the evolution of interactive and personalized learning experiences.

Finally, the box plot in Figure 8 represents how much time participants spent on EDER activities. These data were obtained from the platform's monitoring of participants' activities. The graphical representation offers a comprehensive overview of the time distribution, emphasizing that most activities were completed within 100 seconds, except for a few notable outliers that were longer. These represent cases in which participants may have encountered demanding tasks or exhibited a higher level of engagement with the material, resulting in the need for extra time to finish.

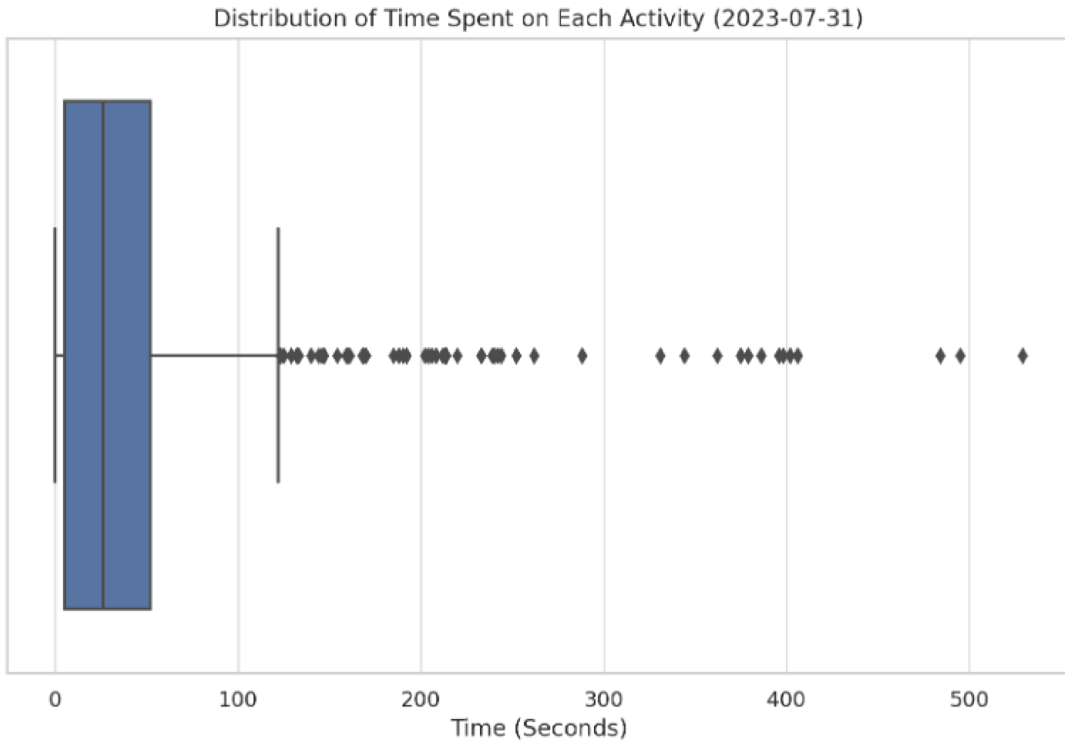

Figure 8. Distribution of time spent on the activities

The implications of Figure 8 for educational practice and research are significant. Understanding the time distribution can help educators gauge the difficulty and pace of activities in escape rooms or similar interactive learning environments. Identifying the activities that consistently take the most time can indicate the need for adjustments in teaching, either by simplifying overly complex tasks or by providing additional resources and support to learners. For researchers, the amount of time spent engaging in activities can be a crucial indicator of the cognitive load of various tasks on the brain and the efficacy of instructional design.

The data in Figure 8 could be leveraged in further iterations to improve the design and execution of educational activities on various learning platforms. Educators and designers can more effectively match challenges to the learner's abilities by analyzing the time spent on tasks, ensuring a balanced and engaging educational experience. Furthermore, incorporating adaptive algorithms that adjust task difficulty based on time metrics could personalize learning experiences, ensuring learners remain engaged without feeling overwhelmed or bored. Thus, Figure 8 sheds light on current participation patterns and provides a model for developing more responsive and adaptive educational tools.

DISCUSSION

Examining participants' progress through an EDER is beneficial, as it helps identify potential difficulties with specific objects or puzzles. Table 1, which displays tracking data from the platform, aids in assessing each learner's performance and the complexity of the challenges. The balance between complex puzzles, especially those that include academic content, and easier ones drives students' progress and motivates them to complete the escape room (Borrego et al., 2017). The tracking provided by EDER Save the Planet addresses the necessity for EDERs to monitor participant interactions in order to facilitate the enhancement of learning experiences through the use of analytics (Lopez-Pernas et al., 2019b). Properly applied, EDERs enable effective monitoring of student CT development.

The EDERs present a fertile field where learning analytics can be applied to evolve these educational resources. Figure 6 illustrates the CT domain via the time students spend answering items in the four challenges. Event history analysis and sequence mining, expressed in timelines, are novel methods for monitoring individual student progress and comparing it with group data (López-Pernas et al., 2022). This coincides with Makri et al. (2021), who state that EDERs strengthen the collection of data from participants by incorporating new tools. In this field, this research contributes by addressing the need for transparent data collection methods outlined by Taraldsen et al. (2022). Learning analytics are effective in measuring student progress in an EDER.

Gradually increasing challenge difficulty is vital in identifying strengths and weaknesses in student competency development. Figure 7 shows performance decreases as students advance through an EDER, possibly due to the complexity of the challenges; however, this should be reviewed in depth because it could be caused by stress or another motivational factor. This observation provides insights into areas beyond CT that require strengthening. EDERs also offer opportunities to address STEM education challenges, encouraging students to think creatively and logically (Sidekerskienė & Damaševičius, 2023). These results confirm the findings of Ouariachi and Wim (2020), who determined that EDERs are capable of addressing hard skills and increasing their knowledge, in this case, CT. In consequence, CT can also serve as a catalyst for the development of other competencies (Jou et al., 2023). This approach develops CT and enhances other transferable skills, providing a more holistic open education experience.

Time management is crucial in analyzing the effectiveness of escape rooms. Figure 8 uses time to understand and classify students' activities. Setting time limits for solving exercises can add a motivational factor to an EDER (Saleh, 2023). According to Lopez-Pernas et al. (2019a), there is no correlation between completion time and increased knowledge. Knowing how long it takes participants to complete activities can help instructors better engage struggling learners and determine which challenges are most appropriate (Helbing et al., 2023). Intervention designs should consider the average time needed to resolve activities to mitigate students' stress.

CONCLUSION

The principal question of the research was "How does the implementation of learning analytics in EDER, focused on SDG-related issues, support the development of CT in Science Club programs?" This research found that timeline, event history analysis, and a method that scrutinizes the student's sequence of discrete states while answering questions allow effective progress tracking.

The study achieved its objective by demonstrating that event history analysis applied to an EDER could measure the CT development of participants in Science Clubs. Moreover, it contributed to identifying other competencies required by users. Suggestions for enhancing high-level competencies include: (a) employ challenge-based strategies like an EDER, (b) gradually increase the difficulty of challenges to monitor competency development, (c) control the time students spend solving puzzles, and (d) continuously evaluate the strengths and weaknesses of the EDER for ongoing improvement. This approach contributes to open education by creating quality open educational resources. This research provides practical specifications to those developing an EDER. The physical model shown in Figure 2 guides the implementation requirements, the logical model (Figure 3) aids in the database creation, and both elements are indispensable in the development of these educational tools.

Regarding the question "What should be the characteristics of escape rooms aiming to develop CT competencies to address SDG-related issues?", this research identified the essential characteristics to be: (a) a responsive design layout for optimal viewing and interaction, (b) accessibility through a range of devices, (c) easy navigation, (d) challenges involving puzzles and time-limited problems, (e) the four sub-competencies of CT embedded in the activities, and (f) focusing the problems on the SDGs.

With respect to the internal design, the logical model that stores the data should be structured using tables to manage user information, including identifiers and credentials. These are essential for personalizing the learning experience and for detailed analysis. The database should store detailed records of challenges, questions, and user interactions. This allows tracking metrics, such as correct answers, interaction times, and overall user engagement. There should be mechanisms for scoring and providing educational multimedia content associated with each challenge to enhance the database further. Enabling the system to handle increasing amounts of data and user interactions efficiently is crucial for scalability. The database must be designed with optimized queries and properly indexed to ensure fast data retrieval and system responsiveness. Measures are needed to ensure system robustness, data integrity, security, and recovery. The database structure is vital for engaging digital escape rooms that offer insights into student learning outcomes.

The main limitation of this study concerns the data. Participating minors opted for anonymity, resulting in incomplete demographic data collection. Also, the study was limited to a single country. However, the potential offered by science clubs (in this case, in two countries) opens up an incredible opportunity to further enhance high-skill CT and complex thinking competencies. Another limitation is the absence of a baseline on the level of CT competency for each student before participating. This provides a guideline for future research involving the use of the escape room with more time for the application of instruments. Other future research could expand the analysis to include qualitative data to measure the participants' experience in the use of the EDER, population samples from clubs in other countries to identify if there are any differences derived from cultural aspects, pre-test y postest application could complement the effectiveness of the EDERs in assessing competencies, finally EDERs could be designed to cover topics from other SDGs.

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