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Open Educational Resources for Computational Thinking: Digital Escape Room

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Abstract

Computational thinking (CT) is an indispensable higher-order competency in our complex, digitalized era; its development in students can be an effective tool for societal problem-solving. This research aimed to use an escape room to develop students' computational thinking using challenges oriented toward Sustainable Development Goal (SDG) 7 of the UN Agenda 2030. The escape room utilized an open educational resource (OER) format to ensure open, inclusive, and equitable education. This research was conducted in five Science Clubs in Mexico, with the participation of 118 high school and higher education students. The CTC4 questionnaire was the instrument to measure their perception of computational thinking. Descriptive and correlational analyses were conducted. The findings highlight (a) the imperative need for strategies that promote the development of digital competencies in women, (b) a need to improve men's perception of their computational thinking development, (c) there is a negative relationship between age and abstraction, and (d) the predominance of pattern recognition development over the other components of CT regardless of the level of digital competence. This work promotes the advancement sought within Education 5.0 to emphasize solutions for the common good. This research may interest educators who wish to implement innovative teaching-learning techniques, instructors who provide training in this field, individuals who want to develop their CT competency, and decision-makers involved in developing high-level competencies.

Keywords: *Complex thinking, educational innovation, higher education, scenario-based learning, digital competencies.*

Introduction

All text must Open Educational Resources (OER) continue to be a powerful tool for disseminating knowledge. The term coined in 2002 by UNESCO has a consolidated definition after years of evolution, practical application, dissemination, promotion, and use: OER are teaching-learning materials but also research materials in any format, disseminated through an open license that allows their adaptation, reuse, and redistribution by third parties free of charge and enables its continuous improvement (UNESCO & Commonwealth of Learning, 2020). Although UNESCO delivered a series of recommendations to achieve progress in Open Education through OER in

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2019, priority attention is still needed (Nova et al., 2022). The recommendations came from the work, study, and awareness of more than a decade of efforts (González-Pérez et al., 2022). Building on the OER efforts can benefit educational inclusion.

OER has multiple formats, including Digital Escape Rooms (DER). Escape room games emerged in informal face-to-face settings in Asia and quickly became popular worldwide (Nicholson, 2015). With the use of gamification for teaching, DERs became a pedagogical opportunity. These are games where participants solve clues and perform tasks to escape a room, often in a limited chronological time (Brown et al., 2019; Nicholson, 2018). This pedagogical tool is used in various areas; this research used it to develop CT.

The study of computational thinking has evolved rapidly. Initial studies focused on how to solve problems using computers or simulating processes, using the mind as a cognitive tool (Hsu et al., 2018; Wing, 2008). Developing CT helps acquire skills such as logic and data abstraction problem-solving to propose solutions (Polanco et al., 2020). CT is a high-level competency that everyone must develop; it comprises a) abstraction: identifying the relevant aspects of a system or problem to represent them in models, b) decomposition: dividing complex problems into smaller, more manageable ones, c) algorithmic thinking: solving problems through a series of logical and orderly steps, d) pattern recognition: finding similarities in the components of a problem or in different problems, and e) evaluation: assessing the efficiency and effectiveness of the solution to computational problems. According to Tsai et al. (2022), abstraction and decomposition are part of the problem analysis phase. This suggests they are used before other components.

This research was conducted in five Science Clubs of Mexico (CdeCMx) venues (Chihuahua, Guadalajara, Guanajuato, Monterrey, and Oaxaca). These clubs offer intensive courses in STEM areas (Science, Engineering, Technology, and Mathematics) and are taught by graduate students, professors, and postdoctoral researchers from the United States and Mexico (Clubes de Ciencia México, 2023). The aim of this research was to use an escape room to develop students' computational thinking using challenges oriented toward Sustainable Development Goal (SDG) 7 of the UN Agenda 2030.

Some studies have paid particular attention to the difference in which men and women develop CT, some have concluded that gender does not influence CT development and assessments (Lee et al., 2017; Oluk & Korkmaz, 2016). However, others argue the opposite (Cruz-Sandoval et al., 2023; Zhao et al., 2021). The differentiator of this work was its focus on SDG 7 as an Education

5.0 effort to develop solutions for the common good. The theoretical framework underpinning this research includes the following topics: OER, DER and CT.

Open Educational Resources

OER must have quality to increase their function as an effective tool for educational inclusion. They contribute to open education through the benefits of free access and the democratization of knowledge. In educational institutions that have a policy in favor of OER their prestige and student enrollment are increased (Chalen et al., 2021), however, despite the multiple advantages of using them and the efforts of various agencies to disseminate them, there are still areas of opportunity in aspects of quality assurance. In other fields, people with diverse roles have benefited from using OER in their training in non-formal education contexts (Colomé, 2019). Knowledge may be a desired good for humanity, but it is not enough to increase OER: quality must be a priority (Bucarey & Aguilar, 2017). Developing, using, reusing and disseminating quality OER is a widespread commitment in formal and non-formal education.

In addition to quality, easy access to OER is essential to effectively contribute to inclusive open education. Although it is not a widespread practice, to meet the demand for OER in different settings, there are higher education institutions that have focused their efforts on the sustainable development of quality resources (Rodríguez et al., 2018). However, the mere fact of making or reusing resources is not enough; the generation of tools and platforms that guarantee their open access and thus improve learning opportunities is required (Ramírez-Montoya et al., 2022). Within these platforms are repositories, dissemination spaces that through the preservation of resources serve as intermediaries for the development of competencies (Tenorio-Sepúlveda et al., 2019). This ecosystem allows OER to exist in a wide variety of formats, such as DERs.

Digital Escape Rooms

DER as OER can be potentiators of knowledge acquisition. The use of DERs has been driven by several factors, including the recent COVID-19 pandemic that forced students to play an active role in the teaching-learning process (Alonso & Schroeder, 2020). DERs became an innovative way to use technology and develop critical thinking with multiple benefits, such as engagement with the learning environment, collaboration, and development of social skills (Makri et al., 2021). DERs can be applied on-site or remotely, in both cases if they have rigorous design, students consider them as engaging and practical activities in the teaching-learning process (Gordillo et al., 2020). A good design of educational interventions with DER can contribute positively to the development of competencies.

DER can be used in educational practices in different areas. With them, the contents can be consolidated regardless of the subject matter because it is a transversal tool for problem solving and computer literacy in a playful experience (Bellés-Calvera, 2022). When used in formal learning environments, they enable the development of higher-order skills such as CT and critical thinking, inspiring students to continuously improve (Botturi & Babazadeh, 2020; Reinkemeyer et al., 2022). In this study, a DER was used to develop students' CT.

Computational Thinking

CT is gaining relevance in this era of constant evolution due, among other things, to its contribution in the solution of technological challenges and its linkage with other high-level competencies. It is a cognitive process that, if fully developed, can generate a higher order skill that plays a preponderant role in the development of other skills (Saltali et al., 2023). CT is increasingly seen as a critical cognition fundamental for people to solve the challenges of today's digital society (Araya et al., 2021). With CT, students can think independently to successfully enter the world of work (Tikva & Tambouris, 2021). CT contributes to the development of complex thinking, a macro-competency composed of the thoughts: systemic, innovative, critical and scientific; indispensable for non-trivial problem solving and conscious decision making.

Studying the way in which CT contributes to the solution of complex challenges is a topic that is gaining interest in the scientific community. The study of CT is a worldwide trend in higher education because of its importance in development and social progress (Liu et al., 2023). Several researches have analyzed CT as a central topic in computer science, mathematics, engineering, robotics and digital skills at different educational levels (Bati, 2022; Esteve-Mon et al., 2020; Guggemos et al., 2022; João et al., 2019; Kiliç, 2022; Polat et al., 2021). Despite increasing efforts to address CT, there is still a need to analyze and promote its transversality in different areas of study. This led us to the research questions: (a) What is the self-perception of science club participants about the development of their digital and CT competencies? We analyzed this from a gender perspective, (b) What is the relationship between age and the perception of each CT component? And (c) What is the relationship between the development of digital competency and CT?

Method

Research Design

Quantitative research was conducted in order to evaluate the data in a numerical manner among elements that are related (Sanca, 2011). In this case, the CT components, digital competence, and demographic data of the participants were considered. A descriptive and correlational study was carried out. The study used an educational scenario-based approach that presents real-life or simulated situations to emphasize practical application and problem-solving skills. The DER was called “Save the Planet”. The game’s challenges were oriented to the Sustainable Development Goals (SDGs) of UNESCO’s 2030 Agenda, specifically SDG 7 (Affordable and clean energy). Solving the challenges develops CT.

The first step was to identify the objective/purpose, as suggested by Doherty et al. (2023), and then the scenario was planned, in this case, the DER, an educational intervention needing a storyline. Canvas supported its design, which had seven points: Learning Objective, Sustainable Development Goal, Components and Points of Interest, Interaction, Learning Evidence, Potential Risks, and Delivery Dates (Molina-Espinosa et al., 2023).

Participants

The CTC4 questionnaire was answered by 118 students who participated in the CdeCMx. Table 1 details the gender of the participants in the five locations. The students’ ages ranged from 14 to 39. Ninety-three (78.81%) were pursuing bachelor’s degrees, 24 (20.34%) were studying for the high school baccalaureate, and 1 (0.85%) had another level of education.

Table 1

Gender of participants

Seat	Male	Female	I prefer not to say	Frequency	Percentage
Chihuahua	8	20	0	28	23.73%
Guadalajara	5	9	1	15	12.71%
Guanajuato	3	14	0	17	14.41%
Monterrey	18	11	1	30	25.42%
Oaxaca	13	15	0	28	23.73%
Total	47	69	2	118	100%

The CdeCMx 2023 research venues occurred in the five states of the Mexican Republic, as shown Table 1.

Data Collection Tools

After implementing the DER, the CTC4 questionnaire (Patiño & Pirzado, 2023) was applied to measure the students' perception of CT development. Before this study, the instrument had been validated in Mexican institutions, therefore, it was not considered necessary to repeat the process. The validity and reliability were realized by Ramírez-Montoya et al. (n.d.), they used expert judgment technique, exploratory factor analysis, confirmatory factor analysis, internal consistency analysis and they calculated Cronbach's alpha (α); their main results were: Kaiser-Meyer-Olkin (KMO = .896), Bartlett's test of sphericity ($\chi^2 = 1716.247$; df = 253 p-value = .000), most items in the analysis of the communalities were close to .5, ranging between .476 and .766, α = .946.

The questionnaire collected student demographic data and their perceived development of digital competency, also through 19 Likert-type questions with five response options (Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree) measured five dimensions of CT: Abstraction (4 items), Decomposition (3 items), Algorithmic Thinking (4 items), Pattern Recognition (4 items) and Evaluation (4 items). The questionnaire requires approximately ten minutes to complete.

Data Collection

Participants were free to participate or not in the research; in accordance with the 1964 Declaration of Helsinki, they participated by agreeing to an informed consent form that they received electronically with the CTC4 questionnaire. The 118 participants returned the questionnaire properly. For the intervention, the researchers first explained to the participants how to use the DER. The CTC4 questionnaire was sent via Google Forms and completed by the participants at the end of the DER session. The researchers were present during the time that the participants were answering the questionnaire in order to clarify any doubts that might arise. Excel was used for data processing, and the data were anonymized to comply with research ethics. The data tabulation procedure is presented in the analysis section.

Data Analysis

The data were initially extracted from the Google Form and subsequently analyzed using Excel. The graphical representation was produced in Tableau. To analyze digital competence, the responses were grouped according to gender and the venue of the participants. For the CT, a numerical value was assigned to the CTC4 responses: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree. Subsequent to the replacement of the alphabetic values with numerical values, the data was grouped according to the CT categories of the CTC4 instrument (Abstraction, Decomposition, Algorithmic Thinking, Pattern Recognition, and Evaluation).

To analyze CT and digital competence by gender, as well as the relationship between the two, we employed descriptive statistics, specifically frequencies and measures of central tendency. This approach enabled us to address the following research questions: What is the self-perception of science club participants regarding the development of their digital and CT competencies? And, what is the relationship between the development of digital competency and CT? Additionally, a correlational analysis was conducted to answer What is the relationship between age and the perception of each CT component?

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Findings

The results are presented according to the topics addressed by the research questions.

Digital Competency and Computational Thinking

Figure 1 shows the participants' perception of the development of digital skills, classified by gender and venue. Digital competence is classified as low, middle and high. Most participants considered themselves to have medium development, especially women. At the Monterrey venue, in contrast to women, men perceive themselves as highly digitally competent

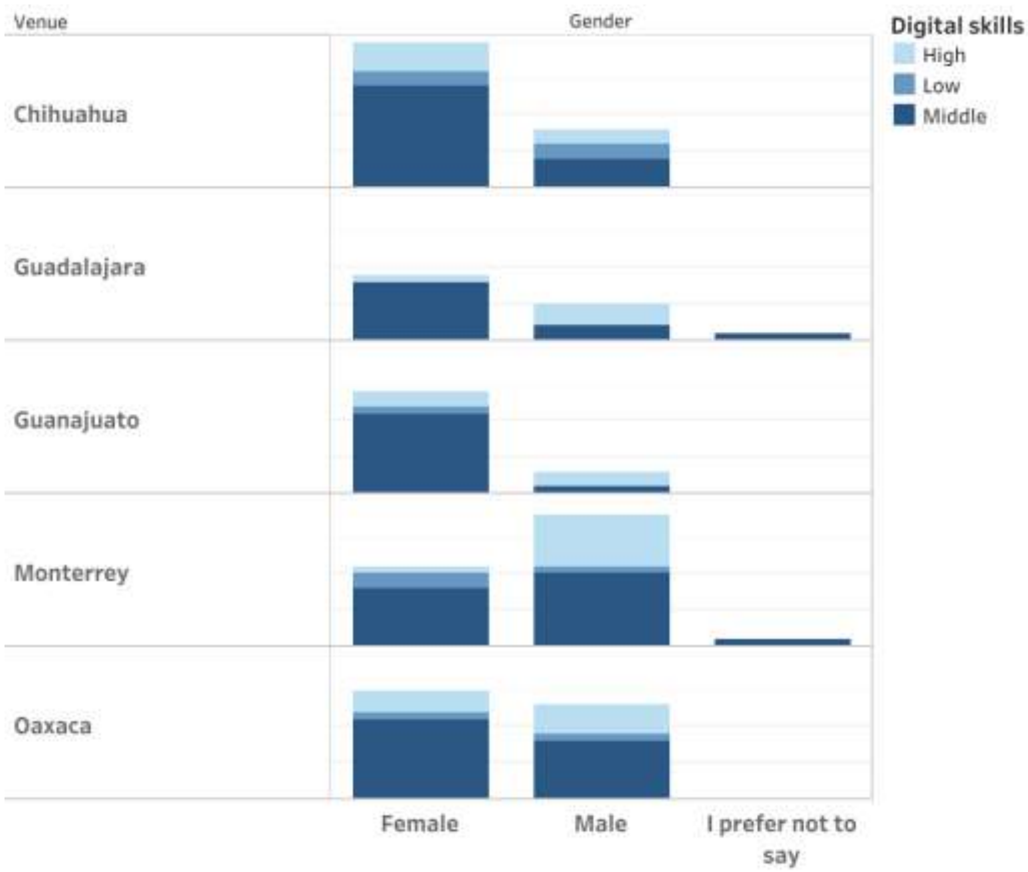

Figure 1. Development of digital competency

Men consider that they have developed their digital competency to a greater extent than women; in practice, this can give rise to a series of strategies to level knowledge among all participants.

Table 2 shows the measures of central tendency of each of the CT competencies, classified according to the participants' gender. The scale is from 1 to 5, where 1 is the perception of the least development, and 5 is the perception of the highest developed level of competency.

Table 2

Development of CT according to gender

Gender		Abstraction	Decomposition	Algorithmic thinking	Pattern recognition	Evaluation
Male	Mean	4	3.9	4.1	4.1	3.9
	Mode	4	4	4	4.25	5
	Median	4	4	4	4.25	4
Female	Mean	3.8	3.8	3.9	4.0	3.9
	Mode	3.5	4	4	4	4
	Median	3.8	4	4	4	4
I prefer not to say	Mean	4.4	3.8	4	4.1	4.1
	Median	4.4	3.8	4	4.1	4.1

This allows us to know the difference in the perception of men and women (and those who prefer not to disclose their gender) regarding their CT development. The most developed competency was pattern recognition, and the least developed was decomposition. This may provide guidelines for developing OER with a particular focus on this issue.

Table 3 illustrates a negative correlation between abstraction and age, indicating that as age increases, abstraction decreases. In contrast, a positive correlation is observed between age and the other CT components (decomposition, algorithmic thinking, pattern recognition, and evaluation), although it is not statistically significant. Evaluation and algorithmic thinking demonstrate the strongest relationship.

Table 3

Correlation of age and CT components

	Age	Abstraction	Decomposition	Algorithmic thinking	Pattern recognition	Evaluation
Age	1					
Abstraction	*-0.0598*	1				
Decomposition	0.0431	0.5796	1			
Algorithmic thinking	0.0946	0.5115	0.5449	1		
Pattern recognition	0.1682	0.4230	0.4522	0.5527	1	
Evaluation	0.0997	0.5204	0.5994	*0.7245*	0.5326	1

Identifying the relationship between age and CT components can contribute to the generation of OER and contextualized educational practices.

Relationship Between Digital Competency and Computational Thinking

Table 4 shows the relationship between digital competency and CT. In the three levels of digital competency (high, medium, and low), pattern recognition was the most developed competency in all cases, while abstraction was the least developed for those with high digital competency, decomposition for those with moderately developed digital competency, and evaluation for those with low digital competency.

Table 4

Development of digital competency and CT

Digital skills		Abstraction	Decomposition	Algorithmic thinking	Pattern recognition	Evaluation
High	Mean	3.90	4.03	4.34	4.55	4.24
	SD	0.98	0.73	0.77	0.74	0.79
Medium	Mean	3.84	3.77	3.92	3.96	3.85
	SD	0.49	0.61	0.60	0.51	0.60
Low	Mean	3.5	3.7	3.63	3.73	3.3
	SD	0.31	0.88	0.59	0.36	0.78

This makes it possible to know the CT areas that should be strengthened as a priority to increase the development of digital competency.

Discussion, Conclusion and Implications

There is an urgent need for strategies that promote digital skills development in women. Figure 1 shows that men perceive themselves as having a higher mastery of digital competency than female participants. This coincides with the findings of Zhao et al. (2021), who observed significant differences in the development of digital competency per gender. Seeking strategies to make digital competency inclusive should be a point of attention in educational practice.

Regarding developing high-level competencies such as CT, women need more confidence. Table 2 shows that women perceived themselves to be less competent than men or those who preferred not to disclose their gender in all CT competencies. This coincides with Cruz-Sandoval et al. (2023), who stated that a gender gap is still present in the development of procedural knowledge, which affects women's perception of their ability to apply knowledge in problem-solving. In the educational field, alternative strategies for developing women's CT must be sought to increase their self-perception in this area, this may lead to more women studying STEM careers.

In general terms, the variable age has minimal influence on how students perceive the development of their CT. As shown in Table 3, age has a negative correlation with abstraction and a low correlation with the other components of CT. This finding contrasts with the conclusions reported by Pan et al. (2024), who determined that students' self-efficacy for CT was moderated by factors including age. Similarly, Kiliç (2022) identified age and other variables, such as gender, as significant factors in the development of CT. However, the findings appear to align with the assertion of João et al. (2019), who contend that age is a crucial factor in the selection of CT teaching environments, with the objective of ameliorating the challenges posed by this condition. The efficacy of educational practices is contingent upon the consideration of the age of the participants.

The ability to solve problems through a series of logical and orderly steps is closely tied to the capacity to assess the efficiency and effectiveness of the solution. As shown in Table 3, there is a strong correlation between algorithmic thinking and evaluation. Similarly, Tsai et al. (2022) suggest that a potential linear relationship exists between these two components. Identifying the relationship between algorithmic thinking and evaluation allows the development of appropriate strategies to complement these skills.

Even if students have developed their digital competences, they need to develop CT to be competitive in this digital age. Pattern recognition was the predominant CT component regardless of students' self-perception of digital competency; Table 4 shows the mean values of 4.5, 3.96, and 3.73 for high, medium, and low perceptions of digital competency. Like the study presented by Esteve-Mon et al. (2020), most students perceived themselves as having medium-high digital competency. This finding suggests that teachers and trainers should implement strategies to develop CT competences, particularly abstraction and evaluation.

The implications for practice are mainly threefold: (a) knowing how students of each gender perceive themselves with respect to the development of their digital and CT competencies can be useful for developing strategies to reduce the knowledge gap; (b) identifying which specific topics require greater attention allows focusing efforts on the development of OER; and (c) knowing the relationship between the development of CT and digital competency generates relevant information for those interested in designing comprehensive educational practices.

DERs are a tool in educational practices with the potential to help develop higher-order skills and competencies. They can be integrated into various areas to achieve learning at different levels of complexity. The aim of this research: to use an escape room to develop students' computational thinking using challenges oriented toward Sustainable Development Goal (SDG) 7 of the UN Agenda 2030 was fulfilled. The research question: What is the self-perception of science club participants in relation to the development of computational thinking and their digital competence? It was resolved by determining that men self-perceive themselves as having more developed CT competences than women; additionally, the CT component that participants have more developed is pattern recognition, this is independent of the level of digital competence they possess.

Placing the DER in open education resources facilitates its use in various contexts and scenarios to develop skills in high school and undergraduate students, as well as those in lifelong learning, contributing to open education. This study identified the imperative need for strategies that promote digital skills development in women; the "Saving the Planet" DER can be used for this purpose. More men perceived themselves as having a high development of CT, which may lead to more complex studies in CdeCMx. Abstraction and evaluation were the least developed components of CT according to the participants' perception, which may indicate the need for greater attention to the other components.

The study's main limitation is the measurement of students' self-perception; future research might employ a comparison of perceptions with skills measurement using the data provided by the DER. Another limitation is the restriction of the research to one year of the Sciences Clubs in Mexico; we suggested that the study be replicated in other editions, similar programs and other countries. Another line of research that emerges from this work focuses on OER and educational practices that develop abstraction in undergraduate students and lifelong learning.

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