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Designing learning experiences on climate change for undergraduate students of different majors

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Education about climate change faces an evolution of the knowledge, and universities should respond with innovative learning processes. As facilitators can adapt to these changes, they will be able to improve learning experiences for students. In this work, learning experiences about climate change were evaluated in undergraduate students without engineering background, as function of the size of the group, duration of the course, gamification activities and technology and virtual tools experiences. The implementation of these activities in the intensive 5-week course focused on climate change education has revealed valuable insights into student motivation, attitude, knowledge acquisition, and engagement. Notably, students' trust in information sources about climate change exhibited variations, with global organizations garnering higher confidence compared to local and personal sources. In a 15-week course exposed to virtual tools (e.g. escape room), the diagnostic test highlighted a 53% understanding level, particularly challenging in numeric aspects. However, the escape room significantly improved results in the final exam, demonstrating a 93% correctness rate, emphasizing the effectiveness of the activities in reinforcing key climate change concepts. On the other hand, the emergence of climate change-themed escape room as an engagement tool demonstrated its potential in enhancing knowledge acquisition and cooperative learning. In addition, Escape room offered an immersive environment that encourages active participation, enabling students to grasp complex climate concepts and solutions more effectively. The study underscores that climate education should go beyond facts, emphasizing universities' crucial role in nurturing the "climate change generation" with the knowledge and motivation for meaningful contributions to climate action and policy formulation.

KEYWORDS

climate change, higher education, educational innovation, gamification, escape room, model Tec21

Introduction

Currently, we recognize that climate change is one of the most significant threats that compromises our development and well-being. At the same time, it has been established that this issue is not adequately addressed by universities, forcing students to rely on the information available online (Eilam, 2022). Social networks and online information can quickly and easily lead to misinformation and skepticism (Treen et al., 2020). Addressing climate change involves transforming the global economy and challenges the vision of a world with libertarian ideals, creating a hostile environment for teaching about climate change.

Climate change education involves learning to comprehend the risk, uncertainty, and influence that the modification of the climatic system has, both on human development as well as the planet (Stevenson et al., 2017). The intricate nature of climate change compels students to understand not only the natural characteristics of the phenomenon but also the associated socioeconomic aspects. Likewise, it is important to consider that the teaching of climate change should also encompass mitigation and adaptation strategies, at both local and global levels, disaster management, and social justice (Stevenson et al., 2017).

Currently, formal education is grounded in the arbitrary division of knowledge into disciplines; and although much has been discussed about the necessity of directing educational systems toward a more holistic and multidisciplinary approach, the reality is that the necessary changes will take more time than needed to address the urgent problems afflicting humanity. Sustainable development, and particularly climate change, requires transdisciplinary approaches that challenge traditional university structures (Mccowan and Mccowan, 2023). The incorporation of topics such as climate change into saturated university curricula demands new and engaging approaches aimed at capturing the interest of students from different fields. Like any academic discipline, climate change must be approached ontologically, epistemologically, and axiologically. Ontology seeks to identify the essential conditions that determine the identity and existence of things; epistemology consists of identifying the procedures that allow us to generate valid knowledge; and axiology seeks to imbue the values of learning into our daily lives (Biesta, 2015). In other words, the process of learning about climate change must lead to a profound reflection that encompasses aspects of being, knowledge, and value (Clarke-Crespo et al., 2021). Therefore, education on climate change should center around the students, with the intention of promoting authentic engagement that imparts relevance and personal meaning, thereby fostering and promoting the necessary behavioral changes.

Studies suggest that the understanding of the global climate crisis depends on individuals' beliefs, sociocultural aspects, political affiliations, norms, and values (Enke and Budke, 2023; Munguia et al., 2023). Therefore, a change in attitude, commonly defined as the stance a person takes toward a particular phenomenon, and behavior which corresponds to the actions individuals take in response to a stimulus, must come about.

In the ever-evolving landscape of education, it is imperative for universities to design new educational programs that holistically address the study of climate change. The incorporation of digital tools becomes paramount in engaging the current generation of students, whose learning preferences lean toward dynamic and interactive activities. Traditional teaching methods risk losing their appeal, making it essential for educational initiatives to adopt innovative approaches. By infusing programs with interactive and technology-driven elements, universities not only cater to the contemporary learning styles but also inspire a genuine interest in the critical subject of climate change among the upcoming generations. This proactive approach ensures that students are not only well-informed about environmental challenges but also equipped with the motivation and tools necessary to actively contribute to sustainable solutions.

The rapid development of technology offers us new and exciting alternatives that not only promote student learning but also enable us to address emerging educational needs. Nowadays, scientific education is considered one of the most integral components of learning, as it fosters important skills such as adaptability and problem-solving (Kalogiannakis et al., 2021). An example of this is gamification, which involves the incorporation of playful elements that enhance student motivation and learning (Deterding et al., 2011; Zimmerling et al., 2019), through a reward system (Al-Azawi et al., 2016). It has been demonstrated that gamification enhances student motivation, fueling a philosophical desire for competition and self-determination (Deterding et al., 2014). Motivation is considered a decisive factor in the learning process, as it correlates with the effort and dedication invested in a particular topic (Buckley and Doyle, 2016). Moreover, gamification contributes to reinforcing information and facilitating the feedback process. Several universities around the globe are pioneering innovative approaches, utilizing gamification strategies to captivate the attention of today's learners. Some noteworthy examples that showcase the fusion of technology, sustainability, and dynamic learning in the realm of climate change education are Climate Change Simulations (Sterman et al., 2012), Carbon Footprint Challenges (Muthu, 2006), Virtual Reality (VR) Expeditions, and Climate Change Escape Rooms (Ouariachi and Van Dam, 2022). These interactive experiences challenge students to solve puzzles, simulate real-world scenarios, track their eco-friendly activities, and complete tasks related to environmental issues within a set timeframe. Moreover, collaborative learning brings academic value, social gains as motivators (Zhang et al., 2022), when combined to game-based learning usually leads to better user retention, deeper learning experience and even competitiveness (Chiotaki et al., 2023). Escape games are defined as an interactive team game, where players uncover clues, solve puzzles, and engage in activities in one or more spaces to achieve a specific goal within a predetermined time (Zhang et al., 2018). Gamification is suggested to enhance students' understanding in the teaching process of climate change, which is a global need. The objective of this work was to explore how technology and digital tools can be used to engage and motivate future professionals to encounter their crucial role in the challenges of climate change and in actively participating in the quest for sustainable development.

Materials and methods

Context of the educational model Tec21, groups details, and monitored variables

Model Tec21 is an educational model launched in the Fall of 2019 by Tecnologico de Monterrey (Campos et al., 2022), a leading private multi-campus university in Mexico, currently ranked in the 29th

global position among private universities according to QS World University Rankings (Quacquarelli Symonds, 2023). Tec21 allows to customize the professional profile of students to acquire a greater set of competencies, which are summarized in the evidence portfolio of all solutions to challenges at the end of their studies. Challenge-Based Learning is composed of three stages: Exploration, Focus and Specialization, and since their first semester, students undergo challenges and develop competencies based on knowledge, skills, attitudes, and values. During the Exploration stage, the students explore a study area to learn and confirm their inclination for a particular major. Depending on the student's interests, they may choose one of 6 possible areas of study: Built Environment, Business, Social Sciences, Creative Studies, Health, and Engineering (ITESM, 2023b).

In this work, third semester students from the exploration stage were considered to determine the engagement and knowledge acquisition about climate change as variables. Engagement was evaluated by applying a survey with 14 statements and a question about confidence on sources of information (Figures 1, 2); while knowledge was evaluated in terms of a diagnosis and a final exam, As described in the section *Data collection and analysis for both groups*. Students included in this study were from two courses: (1) *Causes, Consequences and Solutions to Climate Change (DS1002B)*, and (2) *Ecological Processes for Human Development (DS1009)*. Students from both courses had no background in engineering, nor environmental sciences and were from multiple campuses. In addition, Climate Change as topic is added in the syllabi of both courses. These reasons make suitable context for implementing the educational approach on Climate change. DS1002B had fifty students and it was taught on-line and in English during five-weeks delivering a total 60 h; while DS1009 was a 15-weeks on-line course with same total time but with one-hundred and seven students, a course known as an Elite course. Learning activities done by both groups were similar (Tables 1, 2). However, the DS1009 group had a gamification and digital experience through an escape room entitled "Escape Climate Change" (ITESM, 2023a).

Description of the activities performed in both courses

During the teaching of these courses, different games and recreational activities were carried out and allowed them to accumulate points with which they could access clues and additional support to help them solve the main challenges of the course. The objective of designing this reward scheme was to promote an environment of healthy competition, which would awaken in students will and motivation so that, in addition to understanding the technical complexity of climate change, it also allowed them to internalize the importance of adjusting values and behaviors aimed at promoting mitigation and adaptation strategies to climate change.

The gamification strategy was applied in two different modalities, in Ecological Processes for Human Development the activities were carried out over a 15-week period (about 3 and a half months), while for Causes, Consequences and Solutions for Climate Change, the strategy was carried out in 5 weeks. Although the total hours dedicated

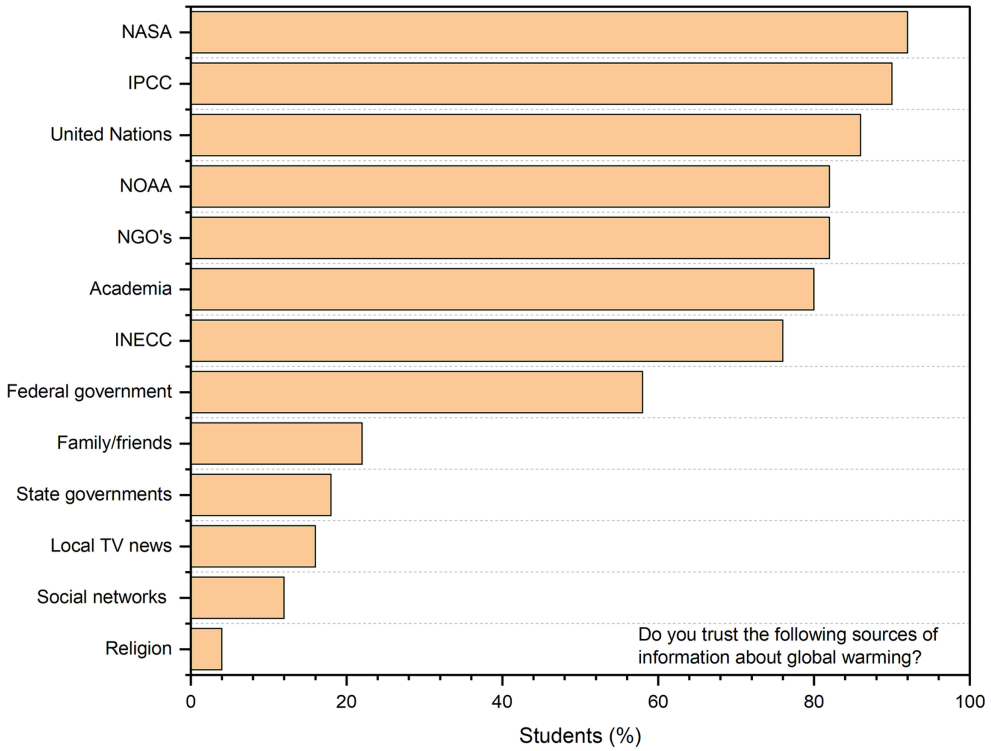

FIGURE 1
Confidence and source credibility of the information related to climate change from students ($n = 50$) attending DS1002B in a 5-weeks intensive course during Spring 2021.

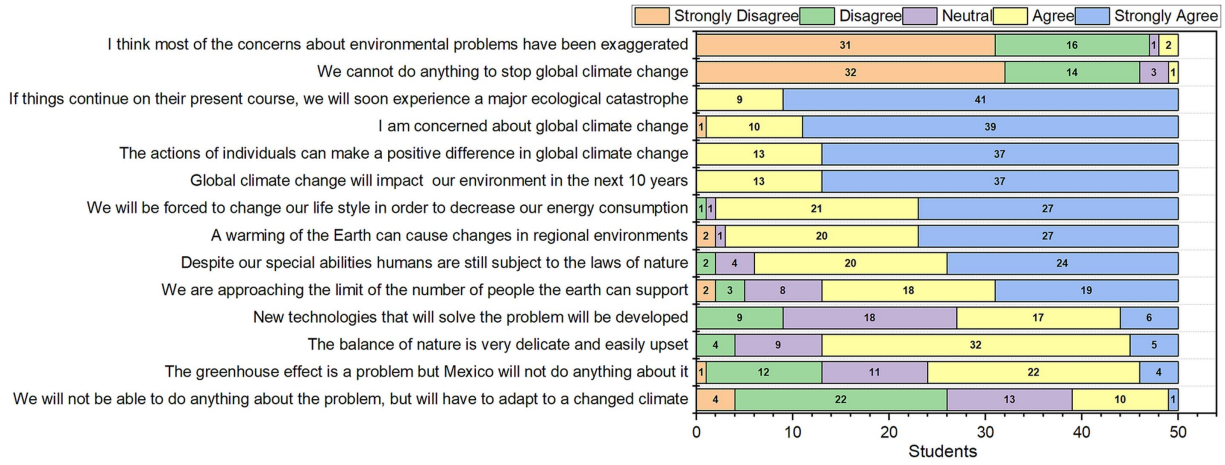

FIGURE 2
Attitude toward climate change from students attending DS1002B in a 5-weeks intensive course during Spring 2021.

to the strategies were the same, we believe that the time and speed necessary to process and mature the ideas presented can be important. Therefore, students from different majors can not only understand the complexity of the subject, but also identify how their discipline can join this global challenge.

In both schemes of courses, students were divided into teams of between 4 and 5 people, to which countries with different positions on climate change were assigned. The organization of the activities in the 5-week course and in the 15-week course are described in Tables 1, 2, respectively. It is important to highlight that the escape room (ITESM, 2023a) was applied only in the 15-week course through 4 missions.

Description of the escape room

The escape room was designed as a portal that could be accessed through a laptop, tablet or cell phone, so that students could contribute to the resolution of the missions in their own time. This was very important, since the students belong to different study programs, with different schedules, in different regions of the country. Within the portal, students could identify which country they belonged to and could communicate with their team members (Figure 3). They could also observe a timer that informed them how much time was left to solve each of the missions, the percentage of progress in the solution and which member of the team had contributed the most, which in addition to promoting motivation and cooperation within the teams to achieve incentives for those who finished first, significantly facilitated the evaluation processes (Figure 4).

Data collection and analysis for both groups

Performance in the activities served to evaluate confidence over the source of information and attitude on the learning process for course DS1002B. This group was not exposed to the Escape Room activity so, to assess the confidence on source credibility of the information related to global warming in this group, a survey with 13 options of international information sources was applied to students in the final exam (post-learning process). In this survey, the following question was included: "Do you trust the following sources of information about global warming?" To evaluate the attitude of students, a survey of 14 statements was incorporated as part of the non-gradable items in the last activity. The possible answers to all the statements were: strongly disagree, disagree, neutral, agree, strongly agree, and followed the scale 1 to 5, respectively. Data was separated by type of answer and plotted as a percentage of students.

The engagement and knowledge acquisition about climate change was evaluated in the DS1009 course, which ran the Escape Room activity during the course. Engagement was demonstrated through their performance in the activities of the Escape Room scenarios, while knowledge acquisition evaluation was analyzed by a comparison between a basic diagnosis about previous knowledge on climate change, and some key questions on the final exam about climate change, its causes, consequences, and potential solutions. Only 6 multiple choice questions were part of the diagnosis, while only 10 out 30 multiple choice questions from the final exam were considered in this study. Data was also divided into type of answer and plotted as a percentage of students.

Results

Implementation of activities in the intensive 5-weeks course DS1002B

DS1002B was implemented as a 5-weeks course during Spring 2020 and Spring 2021. On both occasions, the SARS-CoV-2 pandemic, which began in the spring of 2020, prompted the course's transition to a fully digital format via Zoom. The course implementation varied in group size and teaching language, both potentially impacting student motivation and their climate change perspective. Group classifications included Regular-Small-Local (RSL) groups (students from only one campus or multi-campus) and the Elite-Massive-National (EMN) groups (with around 100 students each from different campuses).

TABLE 1 Activities for the 5-weeks intensive course: causes, consequences, and solutions for climate change (DS1002B).

Activity and assessment type	Learning objectives	Description and expected outcomes
1. Analyze the effects, consequences, and impacts of climate change on the planet and in your community. (Formative assessment).	(1) Understand and analyze the impacts of climate change at both global and local levels. (2) Effectively communicate the effects and consequences of climate change through a visual presentation.	(1) Identify and prioritize the five primary global impacts of climate change. (2) Recognize and document five observable changes linked to climate change within their own respective communities. (3) Build scenarios to enhance the understanding of climate change.
2. CO_2-eq emissions from transportation. (Formative assessment).	(1) Calculate CO_2-equivalent emissions using given emission factors and the concept of global warming potential. (2) Evaluate transportation alternatives based on environmental and economic criteria.	(1) Acquire proficiency in calculating CO_2-equivalent emissions. (2) Assess transportation alternatives, considering both environmental and economic criteria.
3. Analyze the differences between climate change mitigation and adaptation strategies and their utility in generating future scenarios. (Summative assessment).	(1) Simulate and analyze complex climate change scenarios. (2) Create and evaluate scenarios for climate change mitigation and adaptation strategies.	(1) Foster critical thinking and problem-solving skills, promoting a proactive approach to addressing climate change through technology-enhanced learning. (2) Develop a deep grasp of the strategic nuances involved in climate action.
4. Develop a model of a compact, diverse, and sustainable city. (Formative assessment).	(1) Engage in an immersive educational experience focused on urban planning innovation. (2) Integrate diverse aspects of sustainability within urban development.	(1) Gain expertise in designing urban spaces that optimize resources utilization and enhance overall livability. (2) Comprehend the need to harmonize environmental, social, and economic factors.

Notably, EMN instruction was in Spanish, while RSL used English. The first instance of this course hosted 270 students across four groups: two from each type. The EMN groups, which included students from throughout Mexico and other Latin American countries, had a dedicated teaching team of around 6 different professors. In contrast, the smaller RSL groups had only a pair of professors handling the curriculum. This kind of group was considered in this study. All participating students were in their second undergraduate year (3rd semester), majoring in areas like Built Environment, Business, and Social Sciences, indicating they did not have an engineering foundation.

Throughout DS1002B, consistent feedback was essential. The aim was to ensure students understood the expected concepts, acquired the intended skills, and developed the right attitudes, besides validating the authenticity and reliability of global warming-related data. The syllabus encompassed various climate concepts, ranging from understanding the climate system to reviewing real-world examples, like renewable energy solutions. Diverse learning strategies, such as collaborative efforts, in-depth discussions, debates, and role-play, enriched the student experience during the course. All the activities that the students carried out are listed in Table 1; however, this cohort of students did not experience the Escape Room activity.

Motivation and confidence in climate change sources of information

Information on climate change is available from a range of sources, including global bodies (like the United Nations and the Intergovernmental Panel on Climate Change), national organizations (such as the Mexican Federal Government and the National Institute of Ecology and Climate Change), and community-based entities (like local media and religious groups). To gauge how much students trust these sources regarding global warming, they were given a survey during their final exam that featured 13 different sources (shown in Figure 1). The key question posed was: "Do you trust the following sources of information about global warming?." However, 14 additional statements were included to understand the students' perspectives. For each statement, students could respond using a scale of 1 to 5, corresponding to: strongly disagree, disagree, neutral, agree, and strongly agree, respectively.

Students displayed similar confidence levels in global agencies related to global warming, but there was a noticeable difference in their trust in national and local sources among the examined groups (referenced in Figure 1). The most credible sources for all surveyed students were entities such as the Intergovernmental Panel on Climate Change (IPCC), National Aeronautics and Space Administration (NASA), the United Nations (UN), the National Oceanic and Atmospheric Administration (NOAA), various NGOs, and academic bodies. However, sources closer to home, like family, friends, social networks, and local television news, received much lower trust scores, with rates ranging from 12 to 24%.

The RSL student group showed varying trust levels in information sources on global warming, particularly in state and federal governments: RSL students, in general, exhibited low confidence in these entities compared to large and international student group (Morgado et al., 2017). This divergence may stem from the geographical context of their study locations: the city of Monterrey in the Nuevo Leon state of Mexico and Mexico City. International students, being from diverse parts of the globe, might provide a more

TABLE 2 Activities for the 15-weeks course: ecological processes for human development (DS1009).

Activity (Name)	Learning objective	Description and expected outcome
1. The change though images. (Formative assessment).	(1) Analyze the effects of climate change in different geographic regions through the analysis of satellite images.	(1) Recognize that the effects of climate change are highly local, diverse, and complex, which makes it possible to sensitize students to the uncertainty, challenges and risks that climate change poses to the world.
2. Escape Climate Change App: Mission 1. (Formative assessment).	(1) Analyze how the weather works and how climate changes occur.	(1) Comprehend how climate change occurs.
3. Escape Climate Change App: Mission 2. (Formative assessment).	(1) Analyze the goals established in the Paris agreement and learn about the different methods to reduce greenhouse gasses emissions.	(1) Identify and analyze the Sustainable Development Goals. (2) Identify different methods to reduce greenhouse gasses emissions.
4. Escape Climate Change App: Mission 3. (Summative assessment).	Design a strategy to reduce greenhouse gasses emissions, which could allow the countries assigned to the students to achieve the goals established in the Paris Agreement.	Analyze strategies aimed toward the reduction of emissions on a country level, using the Paris Agreement as a basis.
5. Escape Climate Change App: Mission 4. (Formative assessment).	(1) Presentation and discussion of the mitigation and adaptation strategies designed for the country that was assigned to the students in the virtual campus of the Tecnologico de Monterrey.	(1) Visualize the complexities of mitigation and adaptation strategies on a country level so as to be able to present them in a forum style final presentation. (2) Apply negotiation strategies as the representatives of their assigned countries, in order to reach the Paris agreement goals in time.

generalized view of trust in their federal government, while the RSL perspective may be more localized.

Wong-Parodi and Feygina (2020) pointed out that reluctance to accept human-induced climate change can be attributed to factors like preserving socio-economic systems, political beliefs, and prevalent social norms. People often make decisions based on group affiliations and self-perception, rather than objective data. This study's findings resonate with broader research, underscoring a general skepticism toward climate change, especially regarding local information sources in Mexico. Many Mexicans feel that government information on climate change is exaggerated to incite fear and control. This skepticism extends to the belief that individual action is moot without governmental leadership. Improving communication about climate-related achievements, strategies, and research findings to students might increase their acceptance and trust. Furthermore, while emergencies drive immediate responses, the urgency often fades post-crisis.

Lastly, religion emerged as a potential source of information on global warming for some students. Given the diverse backdrop of Tecnologico de Monterrey, further research into the interplay between religion and climate change perspectives is advised.

Attitude and knowledge evaluation

The attitude survey given to the RSL student group revealed encouraging responses (Figure 2). A majority of the students exhibited a positive stance toward climate change, reflected in 6 out of the 14 statements. The attitudes of today's youth are shaped by globalization-driven homogenization and cultural globalization as well as social media, distinguishing them from previous generations. This global identity emphasizes increased awareness of environmental issues and the urgency for sustainable development. While the study showed that students are concerned about the future implications of climate change, many believe that individual actions can make a positive difference. However, there's a prevailing sentiment that nothing can truly halt or reverse the effects of climate change. It's noteworthy that concern for climate change does not necessarily translate into proactive actions for mitigation.

Few studies have explored Mexican students' views on climate change together with students of Portugal and Mozambique (Morgado et al., 2017). Results indicated that there were not significant differences on perception across the board, although Mexican students seemed slightly more skeptical about climate change's occurrence. However, the level of interest in climate issues varied based on nationality, even if the overall interest remained consistent.

Cultural factors, including aspects related to gender roles, age, active learning, and citizenship, significantly influence the perception of climate change issues. Though this study did not delve into socio-cultural elements, future research in this domain is encouraged for a holistic understanding.

Various studies have investigated student perceptions of climate change across diverse populations. There is a prevailing concern among students about the impacts of climate change on their futures and their loved ones. Many express a desire to alter their behaviors to combat climate change's effects. Students' experiences with extreme weather events in their hometowns, as well as their participation in climate-related courses, shape their perceptions about changing temperatures and the causes of climate change.

Universities are pivotal in shaping the "climate change generation" – those who have grown up informed about human-induced climate effects. Yet, misperceptions persist among students, who will eventually be involved in creating and executing global warming mitigation policies. Research suggests that university students' interest in climate change is tied to their need for conclusive answers. Conveying probabilistic data poses challenges, as individuals often interpret data based on personal heuristics, leading to potential judgment errors.

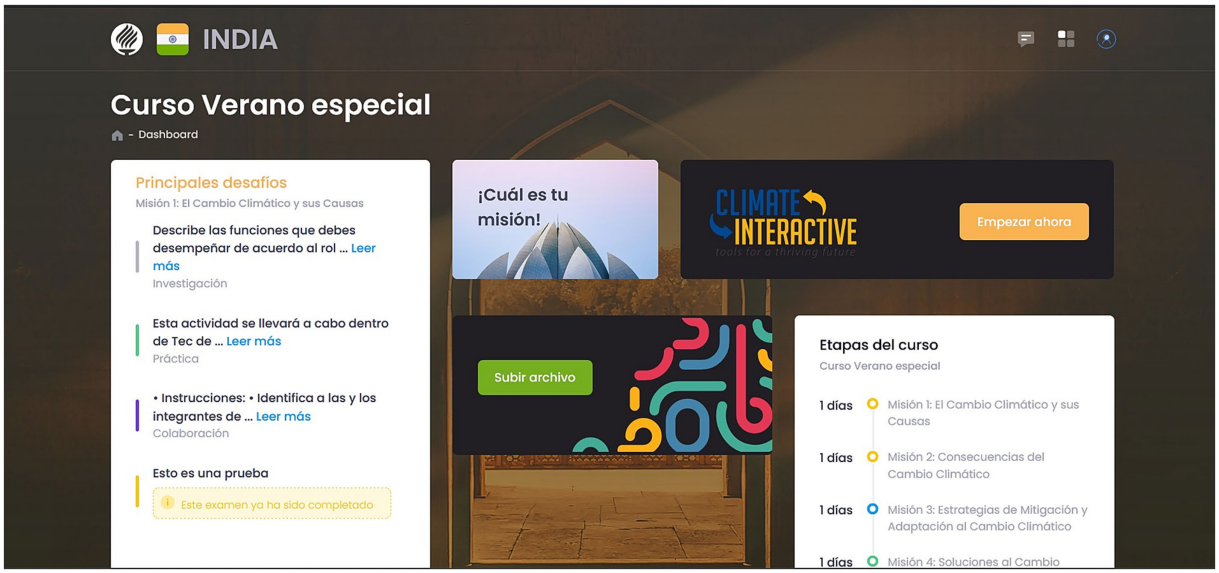

FIGURE 3
Student's view of the escape room used in the DS1009 course.

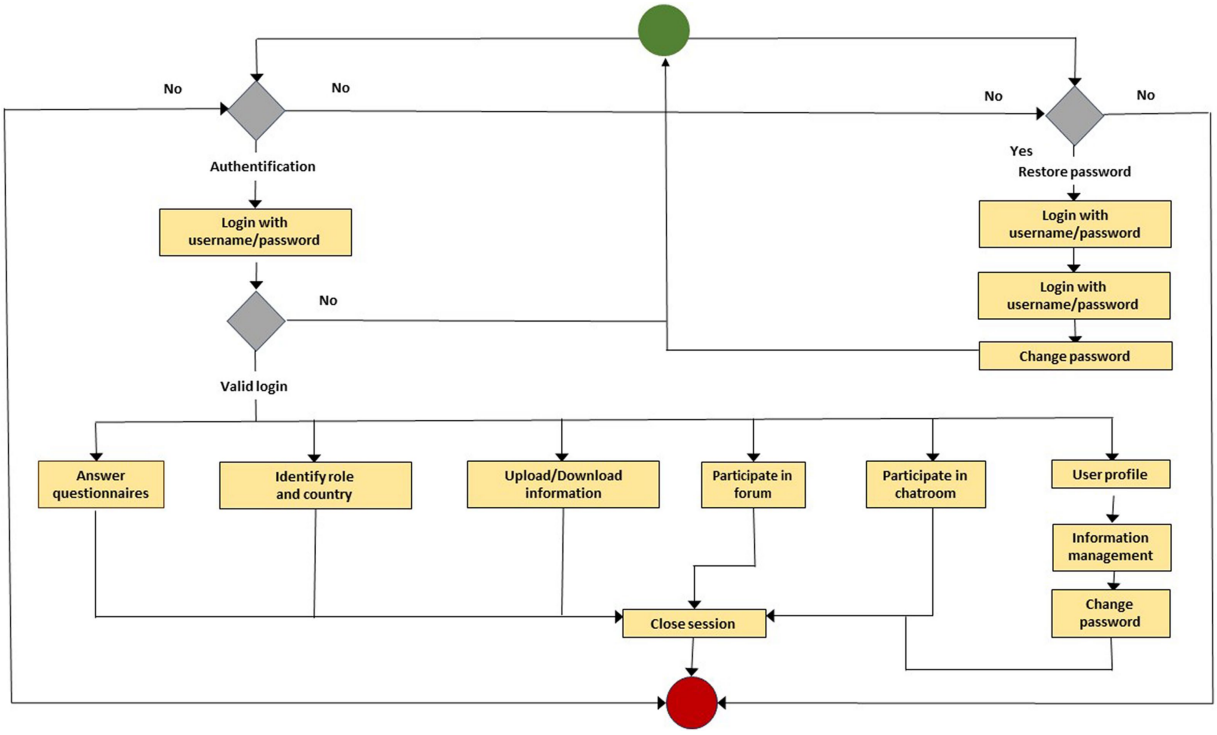

FIGURE 4
Diagram of student activities in the DS1009 course.

Application of escape rooms as a tool to promote engagement about climate change

Motivation

Rousell and Cutter-Mackenzie-Knowles (2020) recognized a demand for inclusive, cross-disciplinary, imaginative, and emotionally-driven methods in climate change education, an area not extensively covered in existing literature. Educators have started to explore the potential of escape rooms for promoting engagement in climate change. Some believe climate change education should focus solely on presenting factual climate science, while others argue for fostering critical thinking and problem-solving skills. This latter group, which has been gaining traction and support, advocates for a comprehensive approach to climate education, encompassing ethical,

humanistic, and interdisciplinary aspects, including social sciences, health sciences, and politics (Ouariachi and Wim, 2020). This last case was implemented in the DS1009 course, which gained the attention of all the students and maintained their interest on the target about "escaping" from climate change over a period of 15-weeks and throughout the 4 missions (Table 2). The participation rate in this activity was 100% and even full classinvolvement, the discussions were turned into "why?" and "what to do" responses in all activities. Therefore, activities must be clearly oriented to climate change causes, consequences and potential solutions, at least for this course, although this also depends on the kind of escape room implemented.

Ouariachi and Wim (2020) presented a comprehensive review of 17 escape room applications related to climate change, and identifies four types of escape room initiatives: (a) Educational escape rooms designed by educators or university sustainability offices for students; (b) Escape rooms designed by students for students; (c) One-day event escape rooms targeting the general public, often related to city plans for sustainability; (d) Escape room products for sale online, targeting either the general public or educators. These products often include puzzles and narratives that can be easily implemented in classrooms. Most escape rooms aim to increase or retain knowledge about climate change, as well as creating awareness about mitigation and adaptation measures. Also, compared to prevalent gamification approaches, like serious games in education, escape rooms stand out due to their emphasis on cooperation.

While many climate change-themed serious games focus on individual skill growth, there's a pressing need to incorporate more cooperative mechanisms to promote collective action and boost efficacy. In escape rooms, players (e.g., students) are directly placed in the game environment rather than controlling an avatar. As a result, the experiential learning derived can be more impactful since there are minimal barriers between the player and the actual experience. However, research is still needed to assess the impact of climate change-themed escape rooms used in classrooms, not just in terms of enhancing environmental awareness and values but also in promoting suitable actions (Ouariachi and Wim, 2020).

Critical knowledge acquisition about climate change

As previously described, a diagnostic test was applied to the group DS1009. The diagnosis consisted of six questions on three main axes: (a) climate change concepts, (b) greenhouse gas emissions and (c) actions regarding climate change effects. Global results indicated that around 53% of the students presented correct answers to the diagnosis (Figure 5), which means that students do not have a solid background on the evaluated axes of climate change. The questions related to numeric values such as the radiative forcing and the carbon dioxide concentration were those with less correct answers, although the effects of climate change and the model predictions were those with the highest percentage of correct answers. This is in line with the global promotion about the effects of climate change and how the predictions forecast different scenarios (Enke and Budke, 2023). At this early stage, it is clear that students have heard the basics causes and effects of climate change, but not the rationale or reasons behind it, such as radiative forcing or carbon dioxide concentration over time, although they do know which kind of gasses cause the greenhouse effect.

Evaluation of the escape room application, which contains the main four activities or missions (Table 2) was performed in a final exam, which had ten questions about climate change which were considered (Figure 6). Global results per question indicate that 93% of the students presented correct answers. Some questions can clearly be compared to the diagnostic test, e.g., main greenhouse gas, confidence over climate change models and radiative forcing, and the increment on such questions are notorious (>40%). Another increment was observed on questions that involve rationale about strategic actions to face climate change, such as those about clean energies, main human activities that generate carbon dioxide, among others. This means that through the activities performed in the escape room, students adopted principles that allowed them to identify and prioritize key actions to face climate change effects. However, the question with the lowest rate of assertiveness (69%) was that related to the concentration of carbon dioxide over time. Although this information was displayed through plots to promote the cognitive process as previously reported (Bui and McDaniel, 2015), this low rate can be attributed to the interleaving of multiple concentrations values of gasses, emissions, regulations and concentrations related to radiative forcing.

Discussion

Participants of both courses gained an in-depth understanding of the effects of climate change through the analysis of reputable sources, such as the "Live Science: Effects of Global Warming" webpage, as can be seen in the results. Individually, participants identified and prioritized the five primary global impacts of climate change, demonstrating their ability to assess and rank the significance of these effects.

In team-based settings, participants recognized and documented five observable changes linked to climate change within their respective localities. Engaging in discussions, they established connections between their selections and the globally identified impacts. Through collaborative efforts, participants constructed a visually impactful presentation comprising of five slides. This presentation comprehensively outlined locally observed effects, consequences, and impacts of climate change, incorporating visual juxtapositions of "before" and "after" scenarios to enhance understanding.

The activity evaluated transportation alternatives through a dual lens of environmental and economic criteria. As participants engaged with real-world scenarios, they acquired the capability to weigh the ecological impact against the economic feasibility of various transportation choices. This skillset not only empowered participants to make sustainable decisions for themselves but also positioned them as advocates for environmentally conscious transportation practices within their communities, allowing them to assess their carbon footprint and devise strategies for emissions reduction effectively. The outcomes achieved reflected the broader goal of fostering environmentally responsible behaviors and informed decision-making.

In the third activity of in the DS1002B course and the fourth one of the DS1009 course, the students successfully accessed the climate change solutions simulator En-ROADS (Siegel et al., 2023). This resource served as a pivotal tool, enabling students to engage in immersive simulations that emulate authentic climate change scenarios (Rooney-Varga et al., 2020). Teams analyzed various influential factors such as energy consumption patterns, the integration of low-carbon energy sources, and ecosystem transformations. Through discussions, participants explored the complexity of these elements and understood their collective impact on the trajectory of climate change.

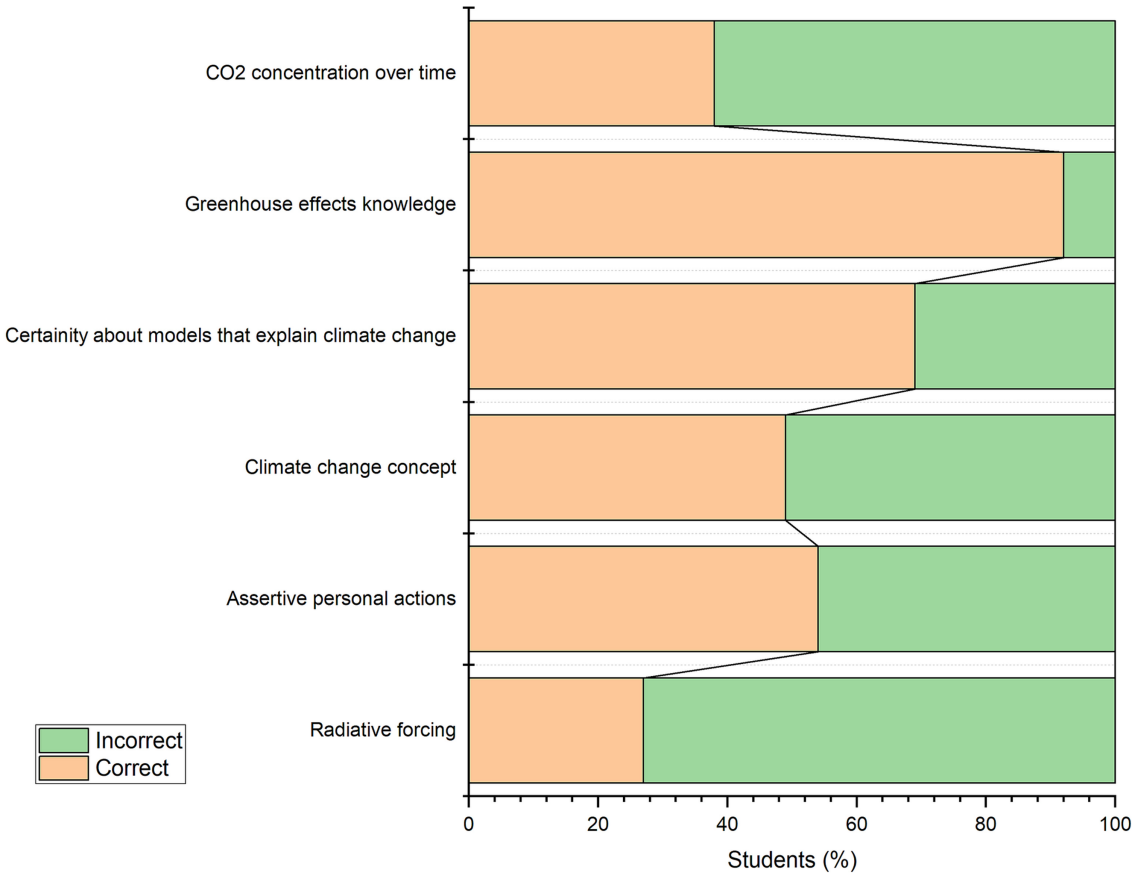

FIGURE 5
Diagnosis prior to the use of the escape room application on the students of the DS1009 Elite group.

Students constructed two distinct scenarios in the following activities. These scenarios became platforms for investigating the potential outcomes associated with the adoption of mitigation and adaptation policies. Notably, the first scenario prompted teams to identify and meticulously outline concrete measures aimed at achieving the goals set forth in the Paris agreement. Each measure was substantiated with real-world examples drawn from international contexts, bolstered by data and quantifiable indicators. The second scenario served as a counterfactual analysis, inviting participants to critically assess the potential temperature escalation if mitigation and adaptation policies were neglected. The juxtaposition of these scenarios underscored the pivotal role that well-informed policies play in shaping the trajectory of climate change. Participants shared their conclusions during plenary sessions, skillfully disseminating their insights. The presentations were marked by a technically sound approach, anchored by references to credible sources, attesting to the depth of research and analysis conducted.

During the fourth activity of the DS1002B course, students acquired an extensive grasp of the fundamental principles that form the foundation for crafting a city model that is both compact, diverse, and sustainable. Through the exploration of concepts like mixed land-use, effective transportation systems, and sustainable infrastructure, participants honed their skill in conceptualizing urban environments that maximize resource efficiency while improving overall quality of life. Furthermore, the students gained insight into incorporating a range of sustainability facets into urban advancement. As they delved into the complexities of shaping a prototype city, they learned the importance of aligning environmental, social, and economic elements. As a result, participants developed a comprehensive viewpoint, empowering them to conceptualize and fashion cities that catered to the requirements of present and forthcoming generations, all the while mitigating adverse environmental effects.

The most notable difference about the application of the escape room in the DS1009 course was the final delivery, which resulted in more engaged students in the Tec Virtual campus. Besides that, WebVR technology is currently very attractive for Rocha Estrada et al. (2022), they were more aware about their role in the plenary session where they showed their initiatives for mitigating and adapting to climate change. Those initiatives were discussed by all classmates and put them in place of agreements of all parties involved in the escape room.

Conclusion

This article addresses a set of practical strategies that educational institutions and educators around the globe can implement to engage future professionals in identifying their role in tackling climate change challenges and contributing to sustainable development. By

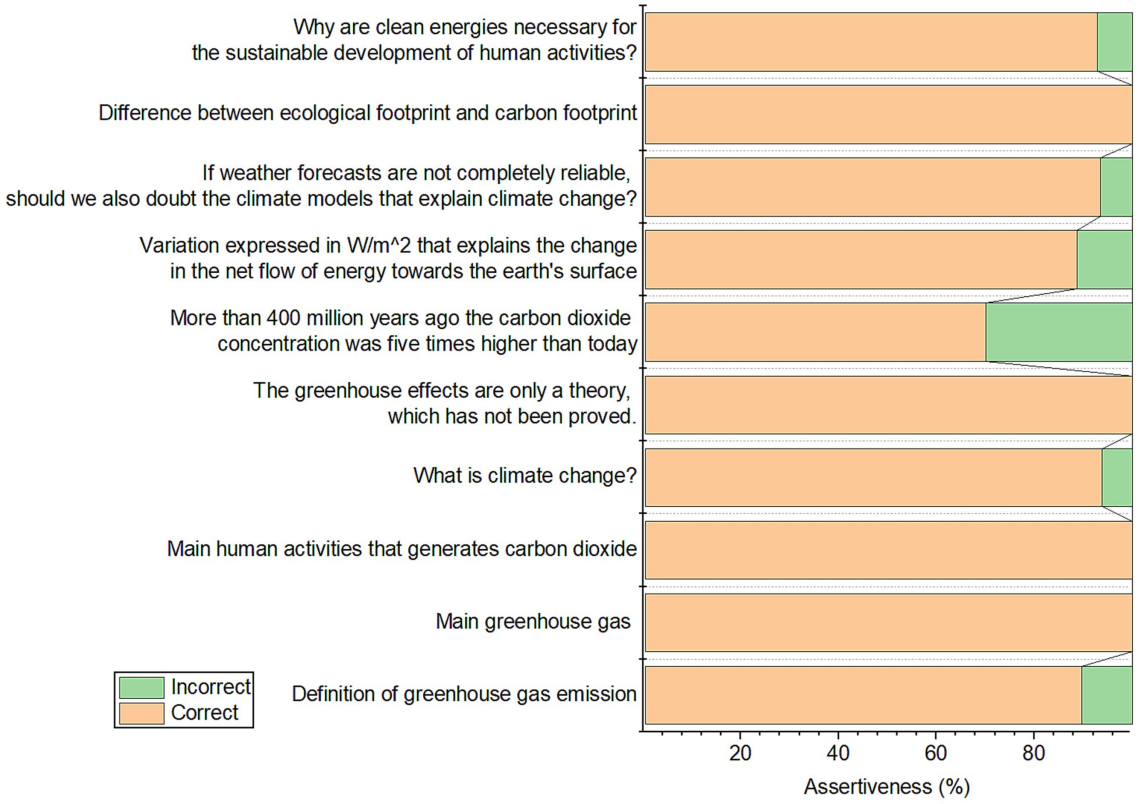

FIGURE 6
Results about knowledge after the application of escape room on the students of DS1009 Elite group.

inspiring students to regard sustainability as an integral part of their future careers and lives, it is anticipated that they will play a pivotal role in shaping a more sustainable and resilient future for humanity. Moreover, the study's outcomes highlight the influence of cultural, geographical, and socio-economic factors on students' perspectives on climate change. Recognizing the skepticism and localized perspectives observed in the RSL student group underscores the importance of tailoring education to address regional concerns and misconceptions. This supports the notion that educational approaches should consider context-specific information dissemination and communication strategies.

In light of the study's findings, it is evident that climate education must extend beyond conveying facts; it should empower students with critical thinking skills, a global perspective, and a sense of agency in addressing climate challenges, and escape room-themed as well as the use of gamification in environmental and climate education can be a driver to promote this. Universities play a crucial role in nurturing the "climate change generation," equipping them with the knowledge and motivation needed to contribute meaningfully to climate action and policy formulation. As the world continues to grapple with climate change, informed and engaged students have the potential to drive meaningful change, both locally and on a global scale.

Cultural factors play an important role in shaping how people view climate change issues, with gender roles, age, active learning, and citizenship being key aspects that impact these perceptions. However, this study did not explore the socio-cultural aspects, previous knowledge acquired, students with background, and further research can include these elements.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

DC-N: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. EC-C: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. PC-A: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. MC-C: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. AV-G: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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