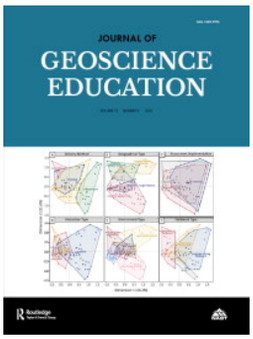

Journal of Geoscience Education

ISSN: 1089-9995 (Print) 2158-1428 (Online) Journal homepage: www.tandfonline.com/journals/ujge20

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To cite this article: Emma L. Kuster & Doo H. Lim (14 Jul 2025): Gamifying climate content to enhance climate literacy: Opportunities for adult learners, Journal of Geoscience Education, DOI: 10.1080/10899995.2025.2531580

To link to this article: https://doi.org/10.1080/10899995.2025.2531580

JOURNAL OF GEOSCIENCE EDUCATION
https://doi.org/10.1080/10899995.2025.2531580

Gamifying climate content to enhance climate literacy: Opportunities for adult learners

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ABSTRACT

Educational games are well suited to tackle the complexity of challenges like climate change because they can simulate complex systems. The purpose of this study is to build upon the work of previous scholars to (a) identify the opportunities associated with the gamifying of climate change content for adult learners and (b) propose how games can further enhance the functional climate literacy of adults. To our knowledge, there is not a review of peer-reviewed literature that assesses knowledge gained or provides a framework for designing these games. We explored the observed impacts of 48 unique climate change educational games and synthesized the work of 53 peer-reviewed journal articles. In general, we noted the games contributed to an increase in knowledge about climate change. Games that implemented a combination of hands-on and digital elements to explore the impacts of future decisions appeared to be the most impactful for increasing climate change knowledge and fostering an action-oriented mindset following the game. Our study also noted that these climate change educational games are primarily designed and implemented for youth and college audiences. This finding is in line with previous research and continues to highlight the need for climate change educational games for adult learners that allow them to bring in their own life experiences and learn how to solve problems that relate to their everyday lives. As a result, we developed a multi-phase framework to guide the development and implementation of climate change educational games for adult audiences.

ARTICLE HISTORY
Received 23 August 2024
Revised 12 June 2025
Accepted 30 June 2025

KEYWORDS
Gamification; climate change; education

Introduction

Several scholars note that climate change education is a key strategy to mitigating and adapting to the impacts of climate change (e.g., Abbasi, 2006; Azevedo & Marques, 2017; McNeal et al., 2014; Stevenson et al., 2017). As one's knowledge about climate change increases, there is an increase in their awareness and concern, which can spur action (Kolenatý et al., 2022). However, imparting knowledge and delivering facts is not enough to increase climate change action (Knutti, 2019). According to the principles outlined by Anderson (2012), educational efforts that promote climate literacy should incorporate active learning, connect to local problems, cultivate problem solving and critical thinking, include narrative techniques, and incorporate risk resilience and a connection to the local environment. The purpose of this paper is to explore the opportunity for educational games to enhance adult learners' ability to make informed and responsible decisions with respect to climate change.

Over the past couple of decades, the number of climate literacy efforts for K-12 learners has increased with new classroom curriculum and nonformal learning opportunities, but the availability of such climate literacy efforts for adults remains lacking (Arndt & LaDue, 2008; Nelson et al., 2022). Climate literacy is defined as one's "understanding of how the climate system works, how human actions influence climate, and how climate influences people and other parts of the Earth system" (USGCRP, 2024, p.2). The rationale for differentiating adult learners from youth and children is substantial. Adult learners are distinct in that they tend to be highly independent and often choose their own learning paths (Bisio, 2022). Additionally, adult learners are more intrinsically motivated compared to younger learners (ELM Learning, 2022). Furthermore, they bring a wealth of life experiences that inform their learning processes, making them more practical and results-oriented in their educational expectations (Knowles, 1984). While some adults may return to school for a formal education (McCall et al., 2018), others seek learning opportunities like workshops or certifications to increase their awareness and understanding of climate change (e.g., Halofsky et al., 2011; Kuster & Miller Hesed, 2024).

According to the 2024 Yale Climate Change Opinion Maps, 72% of adults across the United States think that climate change is happening but only 59% think it is caused by

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humans and only 45% think it will harm them personally (Howe et al., 2015). For this study, we focus our attention on identifying opportunities for adult learners who were likely not exposed to climate change education during their K-12 or collegiate years or who have minimal exposure to climate change education. Our analysis and application of the findings from this literature review are primarily based on two groups of adult audiences that would benefit from a foundational understanding of climate change and its impacts: (1) the general public and (2) professionals in climate-relevant fields (resource managers, adaptation planners, science teachers, etc.).

As we think about developing climate change-based learning events for adults, we need to first recognize that there are several steps between obtaining climate knowledge and subsequently taking climate change action (e.g., making climate-informed decisions). For example, it is helpful to include elements that allow for the discovery of shared values, a connection with one's environmental identity, and an increase of self-efficacy to spur climate-related action (Nelson et al., 2022). To change people's perspectives and behaviors about climate change, adult educators should develop climate literacy efforts that engage the learners in an active manner and make the content personally or professionally relevant. In the end, people need to feel empowered and prepared for action to occur. There are many learning tools and methods being explored for climate change education to enhance one's literacy and increase their likelihood of action, including the use of interactive and educational games.

Gamification, the act of merging instructional content with gaming characteristics (Plass et al., 2015), is useful for making content relevant, interactive, and actionable. Gaming characteristics such as objectives, achievements, point systems, leadership boards, and fictional representations (Warmelink et al., 2020) sets this type of educational programming apart from using technology in instruction (videos, model simulations, etc.). Designing educational games based on game-based learning theory results in games with collaborative learning elements that engage affective, behavioral, cognitive, and social/cultural aspects of the learner (Pivec et al., 2003; Plass et al., 2015). Such educational games promote a better attainment of knowledge because of the active nature of the game (Prensky, 2001).

Educational games, particularly digital games, are well suited to tackle the complexity of socio-ecological challenges like climate change because they can simulate complex systems and promote a systems thinking approach to learning and doing (Lux & Budke, 2020). Additionally, digital and hands-on games that use active inoculation approaches in which learners engage in a two-way dialog with either another learner or a non-player character around a weakened form of misinformation can be used to build awareness and protect against larger sources of misinformation (Roozenbeek & Van Der Linden, 2019). Games that incorporate role-playing elements have also been shown to promote climate literacy (Rumore et al., 2016). Such design elements have the potential to situate educational games as a pivotal teaching technique spanning education for K-12 to adult learners about climate change and action.

Numerous groups have developed climate-based educational games over the past four decades, including the US National Aeronautics and Space Administration (NASA), the US Environmental Protection Agency (EPA), the US National Oceanic and Atmospheric Administration (NOAA), the University Corporation for Atmospheric Research (UCAR), and Climate Interactive, among many others. Even though climate-based educational games have been developed and used by various audiences since the 1980s (Reckien & Eisenack, 2013), the impact of such games on knowledge acquisition and behavior change has only recently been studied in peer-reviewed literature. To our knowledge, there has not yet been a review of peer-reviewed literature that assesses knowledge gained or provides a framework for designing climate-based educational games.

To date, scholars have conducted literature reviews to understand the types of games available and the opportunities they can provide for learning. For example, Reckien and Eisenack (2013) analyzed 52 climate change games that spanned a range of formats from board games to video games, many of which were implemented in formal classroom settings. Their analysis included an overview of the release date, developer type, geographical scope, language, and climate change issues covered in each game. Similarly, Wu and Lee (2015) provided a high-level overview of the benefits and tradeoffs of climate-based educational games, noting that these games are "uniquely suited to get people to understand, care about, and take action on climate issues" (p. 416). A more recent literature review conducted by Flood et al. (2018) went a step further to explore the impact of serious games for climate adaptation decisions. The authors outlined common characteristics of serious games and their impact on learning outcomes from a social learning lens, but did not investigate if game design had any influence on knowledge acquisition or behavior change.

Gamifying educational content for climate change may be a game-changer for increasing the knowledge and action of adults. The purpose of this study is to continue building upon the work of previous scholars to (a) identify the opportunities associated with the gamifying of climate change content for adult learners and (b) propose how games can further enhance the functional climate literacy of adults. Research questions guiding this study include: (a) what types of games have been used for climate education? (b) how does the format of the game (i.e., hands-on vs. digital, collaborative vs. competitive) impact what is learned? and (c) how can games be used to increase the transfer of climate change knowledge into action? By using the information gained through this literature review, educators will be better equipped to design or implement existing educational games as part of learning events for adult audiences like climate-focused workshops, continuing education efforts, or educational entertainment.

Methodology

To begin addressing our research questions, we conducted a narrative review of current peer-reviewed literature examining the impact of educational games on the knowledge

acquisition and behavior change of learners. We adopted the narrative review method because it is useful for providing a comprehensive overview of a topic, identifying gaps in research, and integrating diverse perspectives (Gregory & Denniss, 2018). This method is particularly effective for exploring complex issues that require nuanced discussion rather than quantitative analysis, as was the focus of this effort. Additionally, with complicated words like climate (which can refer to climatology, the conditions of a space, our emotional well-being, etc.) and game (which can refer to athletic games, wildlife, mathematical game-theory, etc.), we took a flexible approach to remove articles from our searches that did not refer to educational games related to climate change. We focused on peer-reviewed literature rather than non-peer-reviewed texts to ensure that the measures used to assess knowledge acquisition had been reviewed by fellow scholars for accuracy and reliability. To search for relevant literature, we used various combinations of the following key words: game, gaming, gamification, gamify, climate, climate change, climate adaptation, global warming, education. Databases used for this review were limited to those available through the University of Oklahoma libraries and included ERIC, Academic Search Complete, Academic Search Premier, Education Full Text, and Google Scholar.

After the 2009 United Nations climate negotiations in Copenhagen, there was a significant increase in the number of educational games around climate change (Reckien & Eisenack, 2013), but relatively few of these have been assessed for short and long-term outcomes on the learner. For our literature review, we chose to focus on peer-reviewed literature from 2010 to present, which represents the period when scholars began assessing and publishing their findings on the learning impact of climate-based educational games. This decision provides some overlap with previous scholars but does not repeat work already conducted. From our initial list of articles, we removed articles that: (1) did not include the implementation of an educational game about climate change, (2) did not include an assessment of participant knowledge acquisition after game play, or (3) focused on the design process itself as the learning mechanism rather than playing the game. In total, 53 articles were selected for analysis.

We classified the articles into three main categories (shown in Table 1) that describe the structure of each study.

Table 1. Classification scheme for the articles included in this study.

Research type	Description
Design and Assessment	Article included a thorough description of the design process for the game and investigated the impact of the game on learning and/or behavior through case studies, evaluation, or quasi-experimental methods.
Description and Assessment	Article did not include the design process but did include a detailed description of the game that was developed by the authors. The article investigated the impact of the game on learning and/or behavior through case studies or evaluation methods.
Assessment Only	Article did not include the design process but did investigate the impact of a game on learning and/or behavior through case studies, evaluation, or quasi-experimental methods.

Of the 53 articles, 18 were classified as Design and Assessment, 15 as Description and Assessment, 20 as Assessment Only. These three classifications and their associated definitions arose from the review itself and capture the range of ways in which scholars are investigating the impacts of educational games on the learners, from designing new games to assessing existing games. The assessments represented include both qualitative and quantitative methods, ranging from case-study to quasi-experimental. Studies that implemented quasi-experimental methods compared the effect of the game on a treatment group against more traditional ways of instruction (lectures, reading assignments, etc.) given to a control group.

As part of our analysis, we created summary statistics to showcase the count of different game types, different audience groups, and different play types represented in the games described and studied in the articles. Play type was defined as the mode in which players of the game interact with one another (i.e., cooperative, collaborative, competitive, or independent). We defined cooperative play to include games designed as multiplayer games in which each player has a specific role but the success (or failure) of the entire game is dependent on all players working together. This definition differs from what we defined as collaborative play, which included multiplayer games where there were no specific roles. These definitions emerged from how games were described in the articles included in this study.

We synthesized the information presented in these articles using the conventional synthesis method (Schick-Makaroff et al., 2016) around three themes which form the structure of our results section: characteristics of climate-based educational games, impact of games on knowledge acquisition, and the transition of knowledge to behavior change. We conclude our synthesis work by presenting a conceptual framework for gamifying climate change content for adult learners based on the analysis conducted in this review. It is possible more articles that fit our criteria exist in peer-reviewed literature but were not available through the databases included for this review.

Study limitations

Our study was limited to available databases through the University of Oklahoma. While this is a limitation, as additional articles may have been available through other databases at other institutions, the articles included in this review that employed similar game types and play types generally noted similar results regardless of their assessment method. Based on the saturation of information we observed in our analysis, we argue that the findings presented here are representative of the short-term learning impact of climate-based educational games. Unfortunately, no articles included in this literature review assessed long-term learning impacts from engagement in the educational game. As such, we are unable to provide insights on how climate-based educational games may influence knowledge acquisition or climate-related action in the months to years following the game.

Table 2. List of unique games included in this study.

Game Name	Climate Concepts (primary in bold)	Audience	Game Type	Play Type	Citation(s)
2020 Energy	**Climate mitigation and adaptation**, Energy efficiency, Energy consumption, Renewable energy, Sustainable development	Youth	Video game	Independent	Ouariachi et al. (2018)
A Planet Near the Abyss	**Climate impacts,** Global change, Impacts to ecosystems, Conservation efforts	College	Board game	Cooperative	Vázquez-Vílchez et al. (2021)
Another Future	**Climate resilience,** Climate policy negotiations	College	Board game	Cooperative	Van Schaik (2023a, 2023b)
Apicum Game	**Climate science,** Impacts on coastal & marine ecosystems, Sustainability actions	Youth	Video game	Independent	Yamada et al. (2019)
Cascade: A Decade of Weather	**Climate resilience,** Hazard preparedness, Risk assessment, Climate impacts	Adult	Board game	Cooperative	Undorf et al. (2020)
Catan: Oil Springs	**Climate resilience,** Externalities (e.g., climate change), Resource dependence, Tragedy of the commons	College & Adult	Board game	Cooperative	Chappin et al. (2017) and Van Schaik (2023a)
Celsius Game	**Climate mitigation and adaptation,** Climate change, Climate policy negotiations	College	Board game	Cooperative	Carreira et al. (2017)
Chill City	**Climate resilience,** Heat planning strategies	Adult	Video game	Independent	Crisman et al. (2023)
Climate Adaptation Game	**Climate mitigation and adaptation**, Climate change, Climate variability, Costs & benefits of actions, Conflicting demands, Impacts on sustainable development	Youth	Role-playing	Cooperative	Neset et al. (2020)
Climate Change Policy	**Climate mitigation and adaptation**, Climate change, International negotiations	College	Role-playing	Cooperative	Paschall and Wüstenhagen (2012)
Climate Change Summit	**Climate mitigation and adaptation**, Climate change policy, Uncertainty in decision-making	College	Role-playing	Cooperative	Stoeth and Carter (2023)
Climate Connected: Outbreak	**Climate impacts,** Climate change, Pandemic response	Adult	Multi-platform (video game & virtual reality)	Independent	Fernández Galeote et al. (2023)
Climate Negotiation	**Climate mitigation and adaptation**, Greenhouse gas emissions, Climate impacts, International negotiations	College	Role-playing	Cooperative	Brown (2018)
CO2peration	**Climate science,** Anthropogenic emissions and consequences, Climate solutions	Youth	Virtual reality	Independent	Harker-Schuch et al. (2020)
Collective-Risk Social Dilemma (variations)	**Climate mitigation and adaptation**, Climate change, Economic development, Negotiations, Free-rider problem	All	Role-playing	Cooperative	Castro Santa (2023), Lamb and Tsigaris (2011), Vicens et al. (2018), and Wang et al. (2020)
Cranky Uncle	**Climate communication,** Climate misinformation	College	Educational app	Independent	Cook et al. (2023)
EcoChains: Arctic Crisis	**Climate mitigation and adaptation**, Carbon emissions, Declining sea-ice, Arctic food web	Adult	Card game	Cooperative	O'Garra et al. (2021) and Pfirman et al. (2021)
Escape the Arctic	**Climate mitigation and adaptation,** Greenhouse gas emissions, Thermokarst	Youth	Digital escape room	Collaborative	Buggé and Resnick (2023)
Estimation Game	**Climate science,** Climate change facts	College	Educational app	Independent	Thacker (2023)
FATE OF THE WORLD	**Climate mitigation and adaptation**, Climate change, Climate policy	Adult	Video game	Independent	Waddington and Fennewald (2018)
Frostpunk: A New Home	**Climate resilience,** Ethical decision-making	All	Video game	Independent	Van Schaik (2023b)
Go-Geocaching	**Climate impacts,** Natural disasters	College	Educational app	Collaborative	Adanalı and Alım (2019)
GREENIFY	**Climate science,** Greenhouse effect, Impacts on local environments, Climate action	College	Online community	Independent	Lee et al. (2013)
Impacts of Climate Change	**Climate impacts,** Sea-level rise	Youth	Role-playing	Cooperative	Ozdinc and Ceyhan (2024)
International Climate Regime Formation	**Climate mitigation and adaptation**, Climate change, Domestic and international politics, Policy negotiations	College	Role-playing	Cooperative	Kauneckis and Auer (2013)

(*Continued*)

Table 2. Continued.

Game Name	Climate Concepts (primary in bold)	Audience	Game Type	Play Type	Citation(s)
KEEP COOL	**Climate science,** Mitigation and adaptation, Climate negotiations, Free-rider problem	Youth	Board game	Cooperative	Eisenack (2012) and Meya and Eisenack (2018)
Lagos2199	**Climate impacts,** Climate change, Sea-level rise	College	Video game	Independent	Keys and Keys (2022)
Lara Game	**Climate resilience,** Water resource management, Negotiations	College	Role-playing	Cooperative	Dinar and McKinney (2010)
LIFE-AMDRYC4	**Climate resilience,** Climate change, Agricultural practices	Adult	Virtual reality	Independent	Hernández-Pérez et al. (2023)
Losing the Lake	**Climate impacts,** Climate change, Water conservation	Youth	Video game	Independent	Nussbaum et al. (2015)
Make it Green	**Climate mitigation and adaptation**, Sustainability	Youth	Board game	Collaborative	Dela Cruz et al. (2024)
Maladaptation in Nordic Agriculture	**Climate mitigation and adaptation**, Maladaptation	Adult	Video game	Independent	Neset et al. (2020)
Migration Mismatch	**Climate impacts,** Climate change, Phenology, Migrating birds	Youth	Board game	Competitive	Argo (2018)
Money Growing on Trees	**Climate resilience,** Climate change, Deforestation, Payments for Ecosystem Services	College	Role-playing	Cooperative	Dissanayake and Jacobson (2021)
Multi-stakeholder Negotiation	**Climate mitigation and adaptation**, Risk assessment, Negotiation	Adult	Role-playing	Cooperative	Rumore et al. (2016)
Ocean Limited	**Climate impacts,** Climate change, Impacts on marine environments, Sustainability-related decision-making	Youth	Board game	Cooperative	Koenigstein et al. (2020)
Ocean Literacy	**Climate impacts,** Eutrophication, Ocean plastic, Sea-level rise	Youth	Educational app	Competitive	Leitão et al. (2022)
Oligotrophic	**Climate impacts,** Ocean as a biome, Microorganisms, Carbon cycle	Youth	Board game	Competitive	Washburn et al. (2021)
Sea4All	**Climate impacts,** Marine and ocean conservation	Youth	Video game	Independent	Alves et al. (2021)
Seattle Sea-Level Rise	**Climate mitigation and adaptation**, Climate change, Sea-level rise	College	Role-playing	Cooperative	Kluver et al. (2018)
Second Life	**Climate impacts,** Water resource management	College	Video game	Collaborative	Law and Jacobsen (2015)
Stop Climate Change	**Climate science,** Climate impacts, Climate mitigation	Youth	Video game	Independent	Idil and Kocak (2024)
SuDSbury	**Climate resilience,** Urbanization, Climate change, Sustainable urban drainage systems	Adult	Board game	Cooperative	Nguyen et al. (2024)
The Climate Trail	**Climate mitigation and adaptation**	All	Video game	Independent	Van Schaik (2023b)
The Survival Games	**Climate impacts,** Biomes, Biological fitness, Climate change	Youth	Board game	Competitive	Rodriguez et al. (2021)
Vindby	**Climate mitigation and adaptation**, Weather, Site investigation, Climate impacts, Costs & benefits	College & Adult	Video game	Independent	Dornhelm et al. (2019)
We Energy Game	**Climate mitigation and adaptation**, Energy use, Urban planning	College & Adult	Role-playing	Cooperative	Ouariachi (2021) and Ouariachi et al. (2018)
World Climate	**Climate mitigation and adaptation**, Climate change, Greenhouse gas emissions, Policy negotiations	College & Adult	Role-playing	Cooperative	Sterman et al. (2015)

Table 3. Count of the game-type included in this study.

Game type category	Count
Role-playing	13
Video game	13
Board game	12
Educational application	4
Virtual reality	2
Digital escape room	1
Card game	1
Multi-platform	1
Online community	1

Table 4. Count of the play-type included in this study.

Play type category	Count
Cooperative	21
Independent	18
Competitive	5
Collaborative	4

Review findings

Within the 53 articles selected for this study, there are 48 unique climate-based educational games (Table 2). These studies are some of the first peer-reviewed articles to investigate the impact of these educational games on the knowledge acquisition and/or behavior change of learners related to climate change content. All the games represented in this review incorporated climate-relevant concepts, including climate science, climate change impacts, climate adaptation, and climate mitigation. Only 18 of the games directly addressed climate change as part of the narrative or game experience, while 30 indirectly addressed climate change through proxies (drought, urban heat island, sea-level rise, etc.) or complex social issues (climate misinformation, international relations, etc.). The climate-relevant content included in each game is shown in Table 2. Instructional content largely depended on the instructor or game designer. However, some games like Multi-stakeholder Negotiation were co-designed with local community representatives to help tailor the game to the needs of the participants (Rumore et al., 2016).

Characteristics of climate-based educational games

The games listed in Table 2 range from card games to games situated in virtual reality. The most common game types represented were role-playing games ($n = 13$), video games ($n = 13$), and board games ($n = 12$). Table 3 shows the breakdown of educational games by game type. Of the games represented, 24 were developed through digital platforms and 24 were primarily non-digital games, but there were a few non-digital games that did incorporate digital elements (e.g., the use of a digital simulation in role-playing). Table 4 shows the distribution of play type, with the most common type being cooperative play ($n = 21$) and the second most common being independent play ($n = 18$) (i.e., single player). The games represented in this review ranged in duration from 15 min to 2+ hours. The majority of games were designed for a single session lasting less than 2 h, but games like Seattle Sea-Level Rise (Kluver et al., 2018), Impacts of Climate Change (Ozdinc & Ceyhan, 2024), Escape the Arctic (Buggé & Resnick, 2023), and Climate Change Policy (Paschall & Wüstenhagen, 2012) were designed to span over several class periods or sessions.

Table 5. Count of the player age represented.

Player age	Count
Youth	16
College	16
Adult	9
College and adult	4
All	3

Table 5 shows the distribution of player age. The most common ages were youth ($n = 16$) and college ($n = 16$). There were nine instances of climate-based educational games being studied with adult learners as the primary audience. There were, however, seven additional studies that did include adult learners as part of the study, in addition to youth and/or college learners. The 16 studies that included adult learners were conducted in non-formal or informal learning spaces and included games intended for the general public, as well as professionals in climate-related fields. Of those, 13 were intentionally designed to result in both knowledge acquisition and spur climate-related actions or decisions.

Common elements seen across the games included a narrative structure, fictional characters, specific objectives to accomplish throughout the game, simulations to make the game more realistic, and a time to debrief after the game concludes. These elements are consistent with the gaming characteristics outlined by Warmelink et al. (2020). Independent and collaborative games did not have "winners" in the sense of an individual or team winning against another live person or team, while cooperative and competitive games required a single winning player or team. With respect to cooperative games, even if everyone technically "wins" the game (e.g., avoids a climatic disaster), there was a single winner or winning team who achieved more points, earned more badges, or had the most money/resources at the end of the game. Of the 13 role-playing games included in this study, 12 required players to either engage in negotiations or make community-based decisions as part of the role-play exercise.

While the majority of the games did not require additional resources, some games were designed to complement traditional course material on a specific topic and allow for an active learning experience to better understand the complex topic. For example, the Ocean Literacy game developed by Leitão et al. (2022) was designed to follow a traditional lecture from the classroom teacher. The Impacts of Climate Change game developed by Ozdinc and Ceyhan (2024) occurs over six lesson hours and provides an opportunity for students to learn concepts through traditional lectures and hands-on activities in the game. We recognize that these designs are not well suited for many adult audiences who may be participating in workshop settings but still find value in their design and ability to influence knowledge acquisition. As was observed by Rumore et al. (2016), role-playing games for adults should be seen as a conversation starter and are strengthened when they are part of larger adaptation planning initiatives.

Impact of climate-themed educational games on knowledge acquisition

Of the articles included in this study, the majority of authors investigated the impact of climate-themed educational games through pre- and post-tests, post-tests only, or satisfaction surveys. Only 11 of the articles utilized a quasi-experimental method with control and treatment groups to test how the game affected knowledge acquisition and/or behavior change. Treatment groups were exposed to the game, while control groups participated in traditional methods of instruction, such as lectures or reading assignments. The games tested with a quasi-experimental set up included two versions of the Collective-Risk Social Dilemma game (Vicens et al., 2018; Wang et al., 2020), FATE OF THE WORLD (Waddington & Fennewald, 2018), 2020 Energy (Ouariachi et al., 2018), Ocean Literacy (Leitão et al., 2022), EcoChains: Arctic Crisis (O'Garra et al., 2021; Pfirman et al., 2021), Stop Climate Change (Idil & Kocak, 2024), Estimation Game (Thacker, 2023), Climate Connected: Outbreak (Fernández Galeote et al., 2023), and Losing the Lake (Nussbaum et al., 2015).

The results of these quasi-experimental studies were mixed, with six studies showing a significant improvement in knowledge for the treatment group, two studies showing small advantages for the treatment group, and three studies showing no difference. For example, Leitão et al. (2022) noted that students who played the Ocean Literacy game after receiving an oral explanation of the marine system had a higher percentage of correct answers on the final assessment as compared to those who only experienced the oral explanation. Similar results were seen with the Losing the Lake game with respect to knowledge gained (Nussbaum et al., 2015). Playing the EcoChains: Arctic Crisis game did not seem to have an impact on short-term knowledge gained as compared to those who read an article on the same topic (O'Garra et al., 2021; Pfirman et al., 2021), but there was an increase in long-term retention of the information for those who played the game (Pfirman et al., 2021). While not a quasi-experimental approach, authors who conducted a pre- and post-test assessments saw an increase in participant awareness, knowledge, and self-confidence related to climate change after engaging in the educational game (Crisman et al., 2023; Rumore et al., 2016; Stoeth & Carter, 2023).

Role of play and game type for learning

The first play type we will review is independent, where learners generally participate as solo actors and play either against or with non-player characters. All the independent games included in this review were based in a digital format (e.g., video games, virtual reality, educational apps). While digital technologies cannot replace the in-person interactions we have with the environment or people, they allow participants to explore places that may not be easily accessible. For example, Leitão et al. (2022) built Ocean Literacy as an educational app for students who live far away from coastal areas so they could explore the impacts of climate change on marine and coastal systems. Similarly, Harker-Schuch et al. (2020) created CO2peration as a 3D interactive game to help learners make sense of complex information related to greenhouse gases and climate change through an immersive story as they travel along with a photon through space. Digital simulations through video games and extended reality help learners safely explore the impact of complex issues like climate change on different locations because it allows them to manipulate the digital space and ask "what if" type questions (National Research Council, 2011).

Six of the independent-style games were designed for a youth audience, four for a college audience, five for an adult audience, one for a mixed college and adult audience, and two for all audiences. In addition to teaching the learners about climate change, several of the individual-style games helped learners recognize the consequences of their individual actions. For example, games like Frostpunk and The Climate Trail introduce the player to the importance of ethical and strategic decisions when they are charged with leading a group of non-player characters as they face extreme events (Van Schaik, 2023b). Similarly, the game Maladaptation in Nordic Agriculture helps learners understand the possible negative implications of their climate adaptation decisions (Neset et al., 2020).

Participants who engaged in the independent games, much like the other play types, experienced an increase in their understanding of climate change (e.g., Harker-Schuch et al., 2020; Nussbaum et al., 2015). For example, we see learners visualizing and understanding the impacts of climate change (Idil & Kocak, 2024; Keys & Keys, 2022), designing sustainable energy systems (Dornhelm et al., 2019), acknowledging their own impact on ecological systems (Alves et al., 2021), and expressing their appreciation and enjoyment in learning (Cook et al., 2023; Hernández-Pérez et al., 2023). As a result of engaging in these games, learners started shifting from repetition to thoughtfulness in their answers related to climate change causes, impacts, and actions (Waddington & Fennewald, 2018; Yamada et al., 2019), increasing their self-efficacy related to climate action (Crisman et al., 2023; Ouariachi et al., 2018), decreasing their feelings of fatalism related to climate change (Lee et al., 2013), and increasing their interest to learn more about the topics explored in the game (Nussbaum et al., 2015). Seven independent games were implemented in spaces where students were also able to engage with each other about their progress and/or work collaboratively as a single team in the game (Alves et al., 2021; Harker-Schuch et al., 2020; Keys & Keys, 2022; Neset et al., 2020; Nussbaum et al., 2015; Ouariachi et al., 2018; Yamada et al., 2019). These studies utilized peer-learning to enhance the learning atmosphere, despite the individualistic style of the play type.

Four games included in our study were classified as multi-player collaborative games, in which learners worked together to accomplish their task. Two of the games were developed for a youth audience and two for a college audience, each one different in their game type. In all cases, the authors observed an increase in the learners' awareness or understanding of climate change because of playing the game with their classmates (Adanalı & Alım, 2019; Buggé &

Resnick, 2023; Dela Cruz et al., 2024; Law & Jacobsen, 2015). The authors noted that after students played Escape the Arctic, there was an increase in student-initiated conversations about climate change in the days following the game (Buggé & Resnick, 2023). Similarly, students that engaged in the Make it Green board game demonstrated an increase in their awareness and understanding of climate change and environmental sustainability concepts through a pre- and post-test assessment (Dela Cruz et al., 2024).

The five games classified as multi-player competitive were designed for youth audiences. Three of these games were designed as board games, one as a role-playing exercise, and one as an educational app. In general, students who engaged in competitive games appreciated the interactive elements (Argo, 2018), improved in their sense of hope about climate change issues (Ozdinc & Ceyhan, 2024), and engaged in more unprompted discussions about climate change following their engagement in the game (Rodriguez et al., 2021). However, this was not the case in all competitive games. In the Ocean Literacy game, the competitive aspect of the game appeared to work against knowledge acquisition. In this case, the students were more concerned with winning the game that they did not spend adequate time engaging with the content (Leitão et al., 2022). Based on these results, a solely competitive game may not be the best design for increasing knowledge if the focus on beating other players is too strong. The Oligotrophic game, however, was recognized by the teachers who implemented the game as one way to address systems thinking with their students since the complexity provided students with a tangible way to understand connectedness within the marine system (Washburn et al., 2021).

The blend of competitive and collaborative aspects is seen in what we define as multi-player cooperative games where success or failure is dependent on everyone playing a specific role and working together. Of the 21 games that we classified as cooperative, three were designed for a youth audience, ten for a college audience, four for an adult audience, three for a mixed college and adult audience, and one for all audiences. Twelve of these games were role-playing games. Role-playing allows for an immersive experience as the participants represent a specific role and start using new knowledge in conversations, debates, and negotiations. For example, in the Climate Change Policy game developed by Paschall and Wüstenhagen (2012), the students' level of knowledge about climate change increased from what the authors called acceptable to impressive. From their perspective, without the role-playing aspect of the game, the students would not have realized that their perceived level of climate knowledge was not enough to carry out meaningful debates.

Eight of the multi-player cooperative games were considered board games and one was considered a card game. Scholars like Eisenack (2012) designed KEEP COOL as a board game to maintain face-to-face communication since they believed this is the most appropriate way to represent and teach how real-world climate negotiations occur. Similarly, Koenigstein et al. (2020) designed Ocean Limited as a board game to maximize social interaction between the players as they progressed through the game. In both studies, the authors note the importance of having face-to-face time in the game to allow for impromptu discussions throughout the game and debriefing following the game.

As a result of engaging in these cooperative games, learners demonstrated a better understanding of climate change and its consequences in our world (e.g., Carreira et al., 2017; Dinar & McKinney, 2010; Paschall & Wüstenhagen, 2012). We see learners gaining knowledge about how: (1) human activity can impact ecosystems (Dissanayake & Jacobson, 2021; Vázquez-Vílchez et al., 2021); (2) communities can adapt to sea level rise (Kluver et al., 2018) and pluvial flooding (Nguyen et al., 2024); (3) climate impacts community risk (Undorf et al., 2020); and (4) domestic and international climate policy negotiations happen (Brown, 2018; Kauneckis & Auer, 2013; Neset et al., 2020; Paschall & Wüstenhagen, 2012; Sterman et al., 2015; Stoeth & Carter, 2023). Cooperative-style games also helped learners begin connecting climate change concepts from the game to reality (Carreira et al., 2017), increasing their sense of responsibility (Meya & Eisenack, 2018), and engaging in peer communication about these issues (Koenigstein et al., 2020; Rumore et al., 2016).

Five multi-player cooperative games centered around personal and group responsibility and action related to climate change, four of which were Collective-risk Social Dilemma (CRSD) games, and one was a Multi-stakeholder Negotiation (MSN) game. In the CRSD games, participants engaged in role-play to decide upon how much they would contribute to climate change mitigation efforts. One scholar observed a gradual decline in cooperation until the players started experiencing losses from climate impacts (Castro Santa, 2023). This is perhaps not surprising given that other scholars conducting this type of game observed unfair levels of contributions from rich nations in the game (Lamb & Tsigaris, 2011) or more advantageous participants in real life (Vicens et al., 2018). Increasing communication between the different groups, however, was seen to improve group success (Wang et al., 2020). In the MSN game, participants engaged in role-play centered around a specific climate adaptation or mitigation challenge. Participants who had less knowledge about climate change to start saw the greatest increase in awareness and concern as they engaged in the role-playing exercise (Rumore et al., 2016).

Cooperative games provide an avenue for learners to explore uncertainty associated with the cooperation between different groups and interests. Uncertainty can be explored safely through games (Costikyan, 2013), including uncertainty in our actions and the actions of others. Games like Catan: Oil Springs (Chappin et al., 2017; Van Schaik, 2023a), Another Future (Van Schaik, 2023a, 2023b), Ocean Limited (Koenigstein et al., 2020), and Climate Change Summit (Stoeth & Carter, 2023) highlight how players' behavior can change during the game as they understand the context, develop empathy, and learn about concepts like competition, managing common resources, and free-riding. Players who must work together for the betterment of all quickly start to understand the importance of cooperation over competition (Carreira et al., 2017), but cooperation can be challenging to achieve. This type of play represents the closest reality to societal challenges (e.g., policy negotiations, competing interests) that we face with climate change and provides learners with both knowledge and action skills.

Transition from knowledge to behavior change

Of the 48 games represented in this study, 24 were specifically designed to spur action or encourage a shift in behavior. The remaining 24 games focused primarily on knowledge acquisition. In the Impacts of Climate Change game, a role-playing game designed for a youth audience, students became more hopeful for the future and motivated to take action on climate change as they progressed through the game (Ozdinc & Ceyhan, 2024). Similarly, A Planet Near the Abyss, a board game designed for a college audience, was found to increase the players' sense of personal responsibility for the environment (Vázquez-Vílchez et al., 2021). Results like these were seen in many of the other games regardless of the game type or play type. When participants practice using the knowledge to make strategic decisions or engage in negotiations, we see them acknowledging perspectives different from their own (Carreira et al., 2017), overcoming doubt in their own knowledge (Stoeth & Carter, 2023), recognizing the consequences of their own actions (Alves et al., 2021; Lee et al., 2013), shifting from individual to collective mindsets (Vicens et al., 2018), increasing acceptance of climate change related actions (Nguyen et al., 2024; Ouariachi et al., 2018), and identifying actions that address climate change issues (Crisman et al., 2023; Koenigstein et al., 2020; Nussbaum et al., 2015; Pfirman et al., 2021). None of the studies included in this review assessed long-term behavior change, so there is limited information on whether these games motivated climate actions in the months to years after their engagement in the game.

Discussion

A goal of climate change education should be to provide people with knowledge about climate change and empower them to take actions that result in positive change (Valladares, 2021). Many climate change curricula, however, focus on providing learners with knowledge and facts and do not help learners transfer that knowledge into practical applications (Knutti, 2019; Reid, 2019). Based on what we observed in this review, the interactive and participatory nature of educational games that imitate real-world processes can influence the player's behavior and help bridge the knowledge to action gap (e.g., Chappin et al., 2017; Kauneckis & Auer, 2013). As was noted by Paschall and Wüstenhagen (2012), games provide learners with an immersive experience where they can learn by doing and reflecting upon the actions they take in the game. The games included in this review provide valuable insight into game design and implementation for any learner, including adults in the general public and professionals for which climate change is relevant to their job duties.

Multiple play and game types exist for climate education

With regards to play type, the most common type observed was cooperative play. Given that success or failure in cooperative games is dependent on groups or individuals with competing interests working together, this play type allows learners to explore key concepts and gain a sense of how we need to work together to overcome the challenges brought on by climate change. For example, Sterman et al. (2015) noted that the role-playing game World Climate allowed participants to invest themselves fully into the discussions and develop a deep understanding of the climate system, as well as ecological, economic, and geopolitical impacts of climate change. Similarly, Castro Santa (2023) argued that cooperative role-playing games can help learners understand the global implications and challenges of engaging in climate mitigation efforts. While it is important that we each individually learn about climate change and understand the impacts of our actions, we must also understand how to work together to address these challenges. In doing so, we begin to recognize the concepts of responsibility and action of different actors (i.e., nations, people groups, corporations, organizations, individuals, etc.). Direct competition between learners, however, in competitive-style games may encourage them to become too invested in winning rather than learning.

Hands-on games, digital games, and role-playing games all have merit and the use of one over the other largely depends on the situation and learning objectives. As we consider the implications of game type, it gets a little more complicated to choose the best approach but there are play types that pair nicely with certain game types and audiences. For example, video games and virtual reality work well for independent-play and may be beneficial to engage adults in the general public. These adults may not be looking to engage in a professional development session with others but are still interested in increasing their understanding of climate change through educational entertainment. Role-playing and board games work well for cooperative-style play and may be beneficial to professionals working in a climate-relevant field who want to learn about climate change and how to effectively engage with different organizations or agencies responsible for managing a specific landscape or resource. Role-playing games, however, do come with some disadvantages that are not generally seen in the other game types. For example, learners who may be more introverted or confused by the material may struggle with sharing their ideas out loud as compared to those who feel more confident (Kluver et al., 2018). Additionally, several of the role-playing games examined in this study spanned over multiple class periods, so there is inherently a larger time commitment involved for the instructors and learners. However, role-playing games can be designed to be shorter based on the needs of the audience. For example, resource managers may not benefit from a role-playing exercise about global negotiations, but they may benefit from one that encourages them to take on a specific role to make a management decision (e.g., Rosendahl et al., 2019).

It is important to note that games do not have to fit into a single type, but rather certain elements may be combined to give the participants the best experience possible. For example, in the World Climate game, the authors combined role-playing elements with a digital simulation to show the implications of greenhouse gas emission proposals (Sterman et al., 2015). The combination of these elements may be

useful for teaching about climate change as we tangibly interact with our environment and others through hands-on means, explore places that may be inaccessible using virtual reality or simulate the impacts of our decisions through a digital model, and engage in social interactions through role-playing.

Game design matters for engagement and knowledge acquisition

The usefulness of playing games to gain knowledge about climate change has been demonstrated, especially for youth and college audiences. Learners playing climate-based educational games partake in a fun, active, and participatory learning experience that will stay with them following their engagement in the game (Brown, 2018; Kluver et al., 2018). If learners feel like they got a lot out of the game, they are more likely to recommend the game to their friends and family as well (Pfirman et al., 2021), thus furthering the impact of the game in spreading knowledge about climate change issues to more people. However, learners may express frustration with the game if they feel like the preparation to play was too much (Dinar & McKinney, 2010). With respect to an adult audience, Rumore et al. (2016) noted that tailoring role-playing games to specific contexts for adult participants is helpful for increasing the value of the exercise and its appeal. Adults who work in natural resource management, for example, would likely resonate more with an educational game that is built around an ecosystem of interest or a certain type of management decision.

Waddington and Fennewald (2018) classified game players into three main categories based on their interactions with the FATE OF THE WORLD and their level of knowledge obtained through play: (1) Embracers—embrace the game's reality and develop a more complex understanding of climate change; (2) Skeptics—express doubts about the game's representation of reality, but still improve their understanding of climate change as a result of playing the game; and (3) Rejecters—express serious doubts about the game's representation of reality and are unable to experience any knowledge acquisition *via* the game. It is important to note that the doubts discussed in their study were not about the science of climate change, but rather the game's representation of reality. If players struggle with the representation of reality, it becomes hard for them to see anything more than the game mechanics and they focus on beating the game rather than learning from the game. When games are done well, learners express their enjoyment and appreciation of the realism and plausibility of the game mechanics (Hernández-Pérez et al., 2023). Games are powerful tools that can help us safely explore an uncertain future (Costikyan, 2013), but we must aim to foster the attitudes of Embracers rather than that of the Rejecters in our game design. Games like Cascade, which was co-designed and played by professionals from a range of local and national government organizations in England (Undorf et al., 2020), can encourage an Embracer attitude through engaging content and connections to real-world decisions.

Useful lessons for adult-focused educational games

Climate-based educational games have been largely used to teach youth and college audiences about climate change and what they can do to address it in their own lives and community. More work is needed to translate the successes of these games into an adult-learning context, but there are many lessons we can take from the work that has already been done. Much like what Reckien and Eisenack (2013) saw in their review, several of the games explored here focused on a relatively simple one-way transfer of knowledge about climate change where participants did not have to respond to different aspects of climate change or forward-looking action. Story-based games that incorporate both knowledge and action have been seen as necessary for effectively responding to a rapidly changing climate (Keys & Keys, 2022). Games that balanced the complexities of climate change with immersive experiences highlighting decision impact provide participants with a unique learning experience. While not all games examined resulted in an increase in climate-based action or an action-oriented mindset, action and action-mindsets were seen when the game itself was intended to influence behavior by having the learners use the knowledge gained in a practical way.

Conceptual framework for gamifying climate content for adults

Based on our synthesis work, we developed a multi-phase conceptual framework (Figure 1) for gamifying climate change content that is relevant to both adults in the general public and professionals working in climate-relevant fields. The framework is divided into three sections: design considerations, implementation, and short- and long-term outcomes. In our framework, we wanted to emphasize active and interactive components to help participants gain climate change knowledge and engage in climate change action by using their new knowledge in a practical way. According to adult learning theory, adult learners come to the learning space with a wealth of experience and seek instruction that is directly applicable to their everyday lives (Knowles et al., 1998). By allowing adult learners to bring in their own experiences to the learning space and situate the learning through a problem-based approach, we can design meaningful climate change educational games.

In the design process, we suggest that there are two elements that need to be considered in parallel when gamifying climate change content: (1) logistical and (2) affective. For the logistical piece, we argue that multi-player games incorporating elements of uncertainty, a collective decision, social responsibility, and social interaction (i.e., collaborative or cooperative games) help learners gain knowledge about climate change and transition from an individualistic mindset to a collective mindset for climate action. Collaborative or cooperative discussions help learners gain empathy for others (Kluver et al., 2018). For the affective piece, we argue that games with more immersive elements of real-world decisions, simplified complexities, practical applications, and

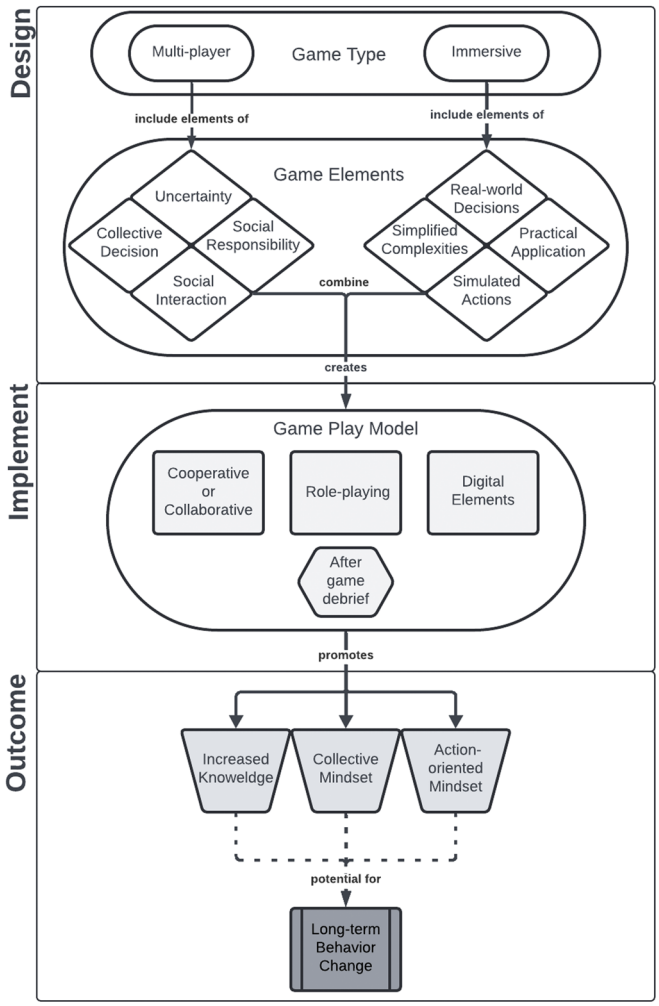

Figure 1. Conceptual diagram of the design, implementation, and outcomes for gamifying climate change content.

simulated actions help move learners from knowledge acquisition to building an action-oriented mindset. The game type that appears best suited to incorporate these design elements is a multi-player collaborative or cooperative role-playing game that incorporates digital elements, where the participants must work together to win the game. The digital element is intended to provide the learners with a safe place to explore the implications of their decisions over time.

Following the game, it is important to debrief and reflect upon the decisions that were made by the participants. Debriefing as part of the implementation phase provides another opportunity for learners to build connections between what they learned in the game and their everyday life or job responsibilities. We argue that this type of set up generally results in increased knowledge about climate change, a shift to a more collective mindset for addressing climate issues, and an action-oriented mindset that allows them to connect the material more easily to action immediately following their engagement in the game. As adult educators, we should strive to inspire hope and action in our learners, rather than contribute to the already existing sense of despair and decision paralysis. The last piece in our outcome section, long-term behavior change, is the goal of climate change education, but unfortunately this piece has not been thoroughly studied, so the connection between the short-term outcomes and this long-term outcome is still relatively unknown.

It is important to note that educational games for adults should be informed by the needs of the audience in mind, as what is relevant to one audience (e.g., natural resource managers) may not be the same for another (e.g., general public). Game designers need to keep in mind the goals and objectives of their audience when deciding on what content should be included, the game type selected, the feasibility and accessibility of certain game elements, and the expected game duration. While not noted in this diagram, independent-style games may be better suited for some adult audiences, like the general public, where they can work through the game at their own pace in non-educational settings (e.g., playing the game as educational entertainment). Multi-player games, on the other hand, may be better suited for adults (either the general public or professionals in climate-relevant fields) engaging in professional development opportunities to increase their knowledge about climate change and enhance certain skill sets (e.g., making climate-informed decisions).

While we did not go into specific design recommendations, we agree with those outlined by Meya and Eisenack (2018): "(i) offer both environmentally friendly and unfriendly decision options; (ii) set winning conditions so that players can win with both kinds of decisions; (iii) introduce game mechanisms that tempt players to follow strategies that are normatively problematic outside the game; (iv) set up the game as a safe space where participants can experiment with different strategies" (p. 330). As we design games, however, we must keep in mind to avoid games that require a steep learning curve with the game mechanics or unrealistic realities. If participants become frustrated with the game, they are less likely to engage. Similarly, as was noted by Crisman et al. (2023), some people simply do not enjoy or perceive games as worthwhile. As such, educational games focused on climate change should be one of many methods that we teach adults about climate change and climate action.

Educational games, like many of those shared in this review, would be beneficial for helping anyone learn more about climate change and begin to make connections with their own interests/responsibilities. Educational games like those shown in Table 2 are useful tools but generally are not the sole professional development tool to teach people about climate change. Those who design and deliver learning events for adults (e.g., a workshop for resource managers, teacher professional development, community education days) may consider including an existing or designing a new educational game as part of the experience.

Conclusions

In this paper, we explored the observed impacts on knowledge and action from 48 unique climate change educational games and synthesized the work of 53 peer-reviewed journal articles to create a multi-phase design framework. In general, we saw that participant knowledge about climate change

did increase following their engagement in an educational game. In some competitive games, however, there was too much emphasis from the participants on winning rather than learning from the game. Cooperative games were the most common game type and allowed participants to experience the importance of working together to address a complex problem.

A range of play types were explored, but role-playing, video games, and board games were the three most common. Games that implemented a combination of hands-on and digital elements to explore the impacts of future decisions appeared to be the most impactful for not only increasing climate change knowledge but also fostering an action-oriented mindset following the game. The hands-on and in-person elements allowed for social interaction during the game, while digital simulations provided participants with a unique experience to test their decisions in a relatively risk-free environment.

Our study also noted that climate change educational games are primarily designed and implemented for youth and college audiences, which aligns with previous research. Based on our findings, we continue to highlight the need for climate change educational games for adult learners that allow them to bring in their own life experiences and learn how to solve problems that relate to their everyday lives. Adults in the general public may benefit from educational opportunities that incorporate games and advance their knowledge about climate change. As they become more aware of the issue, they may support more climate-friendly policies or adjust certain behaviors to be more environmentally friendly. Similarly, adults who work in climate-relevant professions will be able to make better decisions as they become more informed about climate change through active learning experiences like educational games at workshops.

Our multi-phase framework is intended to guide the future design and implementation of climate change educational games that may be used in professional development settings like workshops or for general use as educational entertainment. While our focus was on adults in the general public and professionals in climate-relevant fields, the information provided by the framework may be useful for anyone who desires to create a climate-based educational game. Specific learning goals and appropriate game length are dependent on the purpose of the learning event being planned and the intended audience, but we have developed some general guidance for game designers and learning event organizers to consider. For example, educational games designed to span multiple sessions would not be feasible in relatively short learning events (e.g., hours to days). If a learning event only lasts a half-day, it may be more practical to include a short-duration game (e.g., an hour or less). Additionally, games that address climate change more generally may be better suited for learning events aimed at the general public, whereas games that address climate change in a specific context (e.g., storm surge in a city, resource management decision) may be better suited for professionals in climate-relevant fields who are seeking to make a direct connection between the content and their job duties.

Given the lack of peer-reviewed literature about the long-term behavior change of adults who engage in these educational games, the connection between the game and long-term outcomes remains unclear. Future research on the design framework proposed in this article and on the long-term behavior change of those that engage in climate change educational games would help to advance our knowledge and practice in this field. Additionally, while it was outside of the scope for this article, future research may look to expert opinions on publicly available games that share effectiveness data on their webpages and other non-peer-reviewed sources to help speed up our understanding in this field.

As we have seen throughout this review, research suggests that playing an educational game can improve the player's knowledge about the topic. Recently, however, scholars have also started to investigate the role of designing a game in knowledge acquisition (e.g., Puttick & Tucker-Raymond, 2018; Rousell et al., 2023; Tucker-Raymond et al., 2019). In these studies, students design games to teach others about climate change and in the process, they learn about climate change and develop creative skills. This area of research is still relatively new, and more literature is needed to develop a better understanding of the impact of designing games as teaching tools.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Financial support was provided by the University of Oklahoma Libraries' Open Access Fund.

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