Tampere University

DANIEL FERNÁNDEZ GALEOTE

Gamification and Climate Change Engagement

Building knowledge, developing practice, and studying experiences and effects

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ACADEMIC DISSERTATION
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I understand that authorship has social value. Communicating ideas and producing artifacts takes effort, originality is important, and we should celebrate our unique sensitivities and skills. However, I also like to pay attention to the conditions leading to accomplishment, all the influences, conversations, help, encouragement, basic education, hot meals, and clean clothes provided by countless others, human and not. If we recognize the systemic grandeur of caring for each other, we may discover something far less obvious and more amazing than the fact that someone managed to play their part and toiled away for a few years to put together a dissertation at the end. Then, it may be enlightening to think of creation as the product of untraceable symbiotic processes labored by holobionts. Now, I can start with the revolutionary practice of expressing gratitude, first to those closest to the dissertation.

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Tampere, 2023
Daniel Fernández Galeote

ABSTRACT

Building a sustainable way of life for humans is crucial for the future of life on Earth as we know it, with climate change being a defining and complex, interconnected, and often overwhelming sustainability challenge. Since climate action is both urgent and currently insufficient, widespread citizen implication to enact and demand effective change is needed. Of the multiple methods proposed to support climate change engagement, gamification and games are some of the most intriguing. Although some scholarly study has been done to understand their effects and possible role in tackling this issue, multiple gaps still exist between the tentative optimism in the public discourse and a realistic understanding of their true potential.

This dissertation aims to analyze the state of the art of gamified climate change engagement, including the scientific literature and existing games, and to assess the cognitive, affective, and behavioral engagement effects of a new climate change game, *Climate Connected: Outbreak*, which I designed following best practices. For this, the work is situated at the interdisciplinary intersection between (a) gamification, understood as an umbrella term including also serious games and game-based learning, with its focus on the study of game systems and human motivation, and (b) climate change engagement, which denotes a state of cognitive, affective, and behavioral connection with climate change and typically applies concepts from fields such as psychology, communication science, and pedagogy. The work takes from, and contributes to, all these perspectives, and adds to our understanding of the role of gamification in tackling similarly wicked problems and grand challenges.

The findings are derived from five studies. First, a systematic review of empirical scientific literature (N=64) was conducted, followed by a review of existing digital game artifacts (N=80). Then, based on identified gaps and best practices, the game *Climate Connected: Outbreak* was designed, developed, and implemented as a research artifact. The game's effects were examined both qualitatively (N=12) and quantitatively (N=105), in the latter case in a controlled experiment in which participants were assigned to three groups—text-based control, PC game, and immersive virtual reality (VR) game. The chosen methods approach the phenomenon of gamified climate change engagement from multiple perspectives and focus on diverse objects of study—from literature to games and players.

The findings of this dissertation advance our understanding of the potential of gamified interventions for climate change engagement. Publication I systematically reviews the extant empirical corpus of gamified climate change engagement, with a focus on contexts and populations, designs, outcomes, and research quality. It offers a design agenda that highlights, among other issues, the need for more meticulously designed and reported research; the existence of potentially useful but neglected communication frames; the promising effects of supporting behavior by design; and the fact that audiences are often framed in rigid and conventional ways (e.g., as consumers or professionals), neglecting other possible citizen roles. Publication II analyzes digital games that include climate action and examines the avatar identities and actions in them. The study uncovers six types of avatar identity in these games, including a scarcity of citizen and empowered individual roles, and shows how citizen action in games is typically limited to lifestyle choices and public participation.

With the insights gathered from the previous publications, Publication III describes the use of *Climate Connected: Outbreak*, a single-player, story-based digital game for climate change engagement. The game considers gaps and recommendations such as the use of a health and wellbeing framing, a complex and open understanding of the citizen's identity towards climate change, and the use of immersive VR as an underexplored medium. The results of user research suggest four themes for the participants' serious game experience—continuity, discontinuity, divergence, and topic engagement. Publications IV and V examine and compare the game's and control's effects on learning, climate change attitudes, environmental self-efficacy, and pro-environmental intentions and behavior. The results suggest that games like the one used can be as effective as traditional media in engaging people with climate change while providing a more enjoyable experience, especially in the case of immersive VR. In toto, this dissertation offers a holistic foray into the multidisciplinary area of gamified climate change engagement, offering rigorous studies of literature, games, and player experiences and outcomes as steppingstones to the future development of this area.

TIIVISTELMÄ

Kestävän ja ympäristöä säästävän elämäntavan rakentaminen ihmisille on ratkaisevan tärkeää maapallon tulevaisuuden kannalta, sillä ilmastonmuutos on tulevaisuuttamme määrittelevä, monimutkainen ja usein ylivoimaiselta tuntuva haaste. Tämänhetkiset ilmastotoimet ovat kuitenkin vielä riittämättömiä ja tehokkaan muutoksen aikaansaamiseksi tarvitaan kiireellistä kansalaisosallisuutta. Yhtenä kiinnostavana keinona sitouttaa ja osallistaa yksilöitä ilmastonmuutokseen sekä sen vastaisiin toimiin on pidetty pelejä ja pelillistämistä. Vaikka joitain tieteellisiä tutkimuksia on tehty pelien ja pelillistämisen roolista ilmastonmuutoksen ratkaisijana, julkisen keskustelun alustavan optimismin ja pelillistämisen todellisen potentiaalin ymmärtämisen välillä on edelleen useita tutkimuksellisia aukkoja.

Tämän väitöskirjan tavoitteena on analysoida pelillisen ilmastonmuutossitoutumisen tämänhetkistä tasoa sekä uusimpia suuntauksia tieteellisessä kirjallisuudessa ja olemassa olevissa peleissä. Lisäksi tavoitteena on arvioida suunnittelemani *Climate Connected: Outbreak* -ilmastonmuutospelin kognitiivisia, affektiivisia ja käyttäytymisvaikutuksia yksilöihin. Väitöskirja sijoittuu pelillistämisen ja ilmastonmuutossitoutumisen poikkitieteelliseen leikkauspisteeseen. Työssäni pelillistäminen on kattotermi, joka sisältää myös hyötypelit ja pelipohjaisen oppimisen, keskittyen pelijärjestelmien ja ihmisen motivaation tutkimukseen. Ilmastonmuutokseen sitoutumisella tarkoitetaan ihmisen kognitiivista, affektiivista ja käyttäytymisen yhteyttä ilmastonmuutokseen ja sen vastaisiin toimiin. Termi sisältää käsitteitä esimerkiksi psykologian, viestintätieteiden ja pedagogiikan aloilta. Väitöskirjani pyrkii huomioimaan kaikki nämä näkökulmat edistäen niitä sekä laajentamaan ymmärrystämme pelillistämisen roolista myös muiden samansuuruisten ongelmien ja haasteiden ratkaisemisessa.

Väitöskirjan tulokset koostuvat viidestä tutkimuksesta. Ensimmäisenä toteutettiin systemaattinen kirjallisuuskatsaus empiiriseen tieteelliseen kirjallisuuteen (N=64), jonka jälkeen luotiin katsaus olemassa oleviin, ilmastonmuutosta käsitteleviin digitaalisiin peleihin (N=80). Perustuen näiden tutkimusten löydöksiin, *Climate Connected: Outbreak* -peli suunniteltiin, kehitettiin ja otettiin käyttöön tutkimusalustaksi. Peliä ja sen vaikutuksia tutkittiin sekä laadullisesti (N=12) että määrällisesti (N=105). Jälkimmäisessä tutkimusasetelmassa osallistujat jaettiin

kontrolloidusti kolmeen ryhmään, jotka olivat joko pelin tekstipohjainen toteutus, tietokonepeli tai immersiivinen virtuaalitodellisuuspeli (VR). Valitut menetelmät lähestyvät pelillistä ilmastonmuutokseen sitoutumista useista eri näkökulmista ja keskittyvät eri tutkimuskohteisiin kirjallisuudesta peleihin ja pelaajiin.

Väitöskirjan tulokset edistävät ymmärrystämme pelillisten interventioiden mahdollisuuksista sitouttaa yksilöitä ilmastonmuutokseen sekä sen vastaisiin toimiin. Artikkeli I tarkastelee systemaattisesti empiirisiä tutkimuksia pelillisestä ilmastonmuutossitoutumisesta, keskittyen konteksteihin, populaatioihin, muotoiluun, tuloksiin sekä tutkimusten laatuun. Katsaus tarjoaa agendan, joka korostaa muun muassa tarvetta huolellisemmin suunniteltuun ja raportoituun tutkimukseen. Lisäksi tulisi tarkastella mahdollisesti hyödyllisiä, mutta huomiotta jätettyjä viestinnänkeinoja sekä pelillistämisen potentiaalista vaikutusta tukea yksilöiden käyttäytymisenmuutosta. Katsaus havaitsi myös sen, että tutkimuksissa populaatiot on kuvattu usein varsin konventionaalisesti (esimerkiksi kuluttajina tai ammattilaisina), jättäen huomiotta muut mahdolliset kansalaisroolit. Artikkeli II analysoi ilmastotoimintaa ja ilmastonmuutosta käsitteleviä digitaalisia pelejä sekä niissä esiintyvien avatarien identiteettiä ja toimintaa. Tutkimus paljastaa kuusi avatar-identiteetin tyyppiä, mukaan lukien kansalaisten niukan ja voimaantuneen roolin. Tulokset osoittavat, kuinka peleissä kansalaisten toiminta rajoittuu tyypillisesti elämäntapavalintoihin ja tavanomaiseen kansalaistoimintaan.

Artikkeleiden I ja II tulosten pohjalta artikkeli III esittelee *Climate Connected: Outbreak* -pelin, joka on tarinapohjainen digitaalinen yksinpeli ilmastonmuutossitoutumiseen. Peli ottaa huomioon erilaiset puutteet ja suositukset, kuten terveyden- ja hyvinvoinninkehykset, kansalaisten identiteettien monimutkaisuuden ja avoimen ymmärryksen ilmastonmuutosta kohtaan sekä vähän tutkitun immersiivisen virtuaalitodellisuuden hyödyntämisen. Käyttäjätutkimuksen tulokset muodostavat neljä teemaa osallistujien pelikokemukselle: jatkuvuus, epäjatkuvuus, poikkeavuus sekä aiheeseen sitoutuminen. Artikkelit IV ja V tutkivat ja vertailevat pelin ja kontrolliasetelman vaikutuksia osallistujien oppimiseen, asenteisiin, minäpystyvyyteen sekä ympäristömyönteisiin aikeisiin ja käyttäytymiseen. Tulokset viittaavat siihen, että pelit voivat olla yhtä tehokkaita kuin perinteinen media sitouttamaan ihmisiä ilmastonmuutokseen ja tarjoamaan samalla mielekkäämmän kokemuksen, etenkin immersiivisen virtuaalitodellisuuden tapauksessa. Kaiken kaikkiaan, tämä väitöskirja antaa kokonaisvaltaisen katsauksen pelillisen ilmastonmuutossitoutumisen monitieteiseen alaan, tarjoten täsmällisiä tutkimuksia niin kirjallisuudesta, peleistä kuin pelaajien kokemuksista, muodostaen ponnahduslaudan alan tulevaan kehitykseen ja tutkimukseen.

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Publication II. Fernández Galeote, D., Legaki, N. Z., & Hamari, J. (2022). Avatar identities and climate change action in video games: Analysis of mitigation and adaptation practices. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (pp. 1-18). https://doi.org/10.1145/3491102.3517438

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Publication IV. Fernández Galeote, D., Legaki, N. Z., & Hamari, J. (2023). From traditional to game-based learning of climate change: A media comparison experiment. *Proceedings of the ACM on Human-Computer Interaction*, 7(CHI PLAY), 393. https://doi.org/10.1145/3611039

Publication V. Fernández Galeote, D., Legaki, N. Z., & Hamari, J. (2023). Text- and game-based communication for climate change attitude, self-efficacy, and behavior: A controlled experiment. *Computers in Human Behavior, 149*(2023), 107930. https://doi.org/10.1016/j.chb.2023.107930

AUTHOR'S CONTRIBUTIONS

The following list presents the research contributions of the included publications' authors using the Contributor Roles Taxonomy (CRediT). Leading roles boldfaced.

	DFG	MR	DR	MT	KV	CZ	MD	DL	NZL	JH
Conceptualization	**I-V**	I	I	III					III-V	I-V
Methodology	**I-V**	I		III	III	III	III		II, IV, V	I-V
Software	**III-V**									
Formal analysis	**I-V**			III					I, III-V	
Investigation	**I, II, IV, V**	**I**			**III**	**III**	**III**		IV, V	
Data curation	**I-V**									
Original draft	**I-V**									
Review & Editing	**I-V**	I, III	I, III	III				I	I-V	I-V
Visualization	**I-V**								**I**, IV, V	
Supervision									**I-V**	**I-V**
Project administration	**I-V**									
Funding acquisition	**I-V**								I-V	**I-V**

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JH: Juho Hamari

1 INTRODUCTION

> "[N]ew ecological attitudes and values will remain vaporous if they are not given substance and solidity ... through the tangible realities of everyday life from child-rearing to work and play."
>
> Murray Bookchin, *Social Ecology and Communalism* (2006)

> "Radical intellectuals need to show in detail how alternative futures can be coherently grounded in the deep structures of what already exists, of what people already know and have. Without this exercise, they will not be able to make out a persuasive case for change."
>
> Roy Bhaskar, 'Contexts of interdisciplinarity.' In *Interdisciplinarity and climate change* (2010)

> "The garden you grew today felt different. You learned something. And you also gave something back. A fine day's work. Stick with it, my girl…"
>
> Nonno, *Mutazione* (Die Gute Fabrik, 2019)

Sustainability is a crucial issue of our time and a requirement for a livable future, with its importance having been intuited or acknowledged for centuries. The genealogy of modern Western environmentalism as a social and political movement has been traced back to the British Romantics (Davies, 2018), environmental protection laws as a result of the UK's industrialization (Damon, 1955), and nature conservation initiatives in Europe, its colonies, and the US (Barton, 2002; Britannica, 2023). Even so, environmental concern has manifested in human societies around the world throughout the Common Era (Britannica, 2023) and in the ancient world (Hughes, 2014). Most importantly, indigenous peoples have lived for thousands of years without significantly depleting or degrading the ecosystems around them (Ellis et al., 2021). Thus, ecological awareness is far from a modern Western invention.

However, and in line with the manifest environmental impacts of contemporary economic development, the recent history of sustainability is one of growing awareness and risk. In the 1960s, the book *Silent Spring* imprinted human environmental impact into the American public's consciousness (Carson, 1962), while *Our Synthetic Environment* warned of the risks of pollution for human health

(Bookchin, 1962). In 1972, the report *Limits to Growth* warned of the contradiction between infinite growth and a finite planet (Meadows et al., 1972). In 1987, *Our Common Future* (World Commission on Environment and Development [WCED], 1987) exposed that human development as a political and social issue could not be separated from environmental consciousness, and proposed a broad definition of sustainable development that is used to this day: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 54). Especially from the 1992 Rio Earth Summit onwards, multiple global initiatives, including unprecedented accords such as the Paris Agreement, have been put forward to try to limit various human ecological impacts, with the most recent developments advocating for a justice lens that acknowledges asymmetries in responsibility, capacity, and risk (Intergovernmental Panel on Climate Change [IPCC], 2022a). While some successes have been attained in, e.g., protecting the ozone layer (United Nations [UN], 1987) and, prospectively, the high seas (UN, 2023), acting on other issues such as limiting anthropogenic climate change has encountered serious difficulties attributed to complexity (Levin et al., 2012) and to powerful vested interests maintaining business as usual (Stoddard et al., 2021).

Thus, it is natural that scientists and parts of society have developed an interest in the possibility of societal collapse, even during this century. Sustainability has transcended concern with future generations, as it has become clear that present development directly affects the needs of present generations (IPCC, 2023). We are crossing multiple planetary boundaries (Steffen et al., 2015) and risk activating devastating climate tipping points, some of which are unaccounted for in typical forecasting models (Ripple et al., 2023). Therefore, a system-wide transformation of socioeconomic practices and structures is needed, but it is not currently occurring (United Nations Environment Programme [UNEP], 2021). Since human history offers multiple examples of civilizational collapse, contemporary collapsologists warn that modern societies are not immune to it, that a downfall could occur in a few years or decades, and that it could be precipitated by multiple interrelated crises, not least an ecological one (Servigne & Stevens, 2015). In this context, it becomes urgent to promote socially sustainable future narratives, or ways of "collapsing better" (Ecologistas en Acción, 2022), if we are to avoid adopting a survivalist ethos (Charbonnier, 2019) or an ecofascist one (Cawood & van Vuuren, 2022). Thus, in our century, the central sustainability question (meeting the needs of the present without compromising our future) challenges us on the flourishing, and even existence, of the human species and the biosphere as we know—or knew—it.

As hinted, climate change is one of the defining sustainability issues of our time. Its complexity, interconnectedness and magnitude make it a sociopolitical conundrum and an ethical question as much as an object of scientific inquiry and argumentation (Rommetveit et al., 2010). To determine the adequacy of climate solutions, it is not enough that they effectively curb greenhouse gas emissions, but the affected people's roles, beliefs and material conditions must be considered (Incropera, 2015). Perhaps more than with other ecological crises, issues of power and insufficiency of existing laws and institutions complicate addressing climate change (Levin et al., 2012). This makes it representative of grand challenges that necessitate large-scale cooperation and of wicked problems with no single, agreed upon and definitive solutions (Incropera, 2015).

Despite its challenges, climate action is urgent. Global warming represents a threat to vital human and non-human systems (IPCC, 2021), which has direct consequences for our well-being (Romanello et al., 2022) and that of life on Earth (UNEP, 2021). The scars of climate change can be seen in our tangible world (IPCC, 2022a), but also in our psyche (Wray, 2022). Even when framed mostly as a future issue, which is less and less realistic given its past and present global impacts (IPCC, 2022b), the "future-canceling" effect of climate change has serious impacts on the way that we perceive our daily lives and present actions (Collings, 2014). Unsurprisingly, then, climate change is not only considered a top global threat by scientists, but also by citizens around the world (Poushter et al., 2022).

The mitigation potential of several measures and mechanisms across all sectors of human activity has been studied and calculated (IPCC, 2022b; Project Drawdown, 2023). In practice, though, different ways to confront sustainability challenges have been proposed. To attain a socio-economic system that supports human well-being in a thriving natural world, which seems to be indeed possible (Raworth, 2017; Vogel et al., 2021), proposals range from ecomodernism to degrowth. Ecomodernism focuses on "green" technological innovation, efficiency, and intensification of human activities rather than "harmoniz[ing] with nature" (Asafu-Adjaye et al., 2015, p. 6). Meanwhile, degrowth proposes "the democratic transition to a society that—in order to enable global ecological justice—has a much smaller throughput of energy and resources, and thus also a smaller economy; ensures justice, self-determination, and a good life for all under this changed metabolism; and does not depend on growth and continuous expansion" (Schmelzer et al., 2022). It seems clear, however, that a model striving to protect life on Earth will require weaving both mitigation and adaptation into the core of our future action and doing so through international cooperation and inclusive governance (IPCC, 2023). Whatever its socio-political concretization, this change would be radical (UNEP, 2021).

Making this change democratic requires, rather obviously, widespread citizen implication. It has been proposed that transforming processes and physical structures should be accompanied by cultural transformations as well, starting with a shift from market values to biophilic ones in our relationships to nature (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2022). Pragmatically, for citizens to support and demand radical change, engagement is needed; that is, a connection with climate change, including cognitive, affective, and behavioral aspects (Lorenzoni et al., 2007). This includes individual actions and habits, but also public participation (Paas, 2016) and enacting a variety of citizen roles (Wibeck, 2014).

Multiple methods have been proposed to support climate change engagement. The traditional route, termed "the information deficit model," assumes that lack of engagement results from lack of knowledge, and that the central solution is better communication from experts to the public. However, this strategy has been "highly criticized for being overly simplistic and inaccurately characterizing the relationship between knowledge, attitudes, beliefs, and behaviors, particularly for politically polarized issues like climate change" (Suldovsky, 2017). In contrast, more recent developments propose considering deep and careful forms of engagement, mental models of climate change, and relevant social norms in climate change communication (Goldberg et al., 2020); framing messages in accordance with audiences and contexts (Bain et al., 2012); considering emotions (Brosch, 2021; Schneider et al., 2021); and relying on experience and dialogue rather than one-directional communication (Monroe et al., 2019; Wibeck, 2014; J. Wolf & Moser, 2011). This last point leads to interactive, experiential, inquiry-based, and constructivist methods (Monroe et al., 2019; Sterman, 2011; Wibeck, 2014), including gamification. Games and gamification are not only typically suitable for experiential learning (Krath et al., 2021) able to adapt to player performance and encourage exploration (Plass et al., 2015); they can also result in positive (Cairns et al., 2014) and meaningful experiences (Oliver et al., 2016) and motivate real-world action (Krath et al., 2021). Therefore, gameplay is a complex act through which climate change can be related to cognitively, affectively, and behaviorally.

Despite gamification's potential, a question often lingers—How can play be invoked in relation to matters as serious as climate change and other ecological crises? Precisely, various authors have identified the need for joy, pleasure and play in a sustainable future. This includes the concept of Epicurean environmentalism, which focuses on the pleasure of living well through non-repressive frugality and other measures (Riechmann, 2015). This notion resembles degrowth's "more meaningful and less destructive forms of happiness" (Schmelzer et al., 2022) and the dyad individual sobriety-social unproductive expenditure for a collective good life (D'Alisa et al., 2014). Similarly, play should be considered if we are to articulate new values and attitudes (Bookchin, 2006). Thus, a sustainable life, which is one engaged with climate change, may entail playing different games than we do today, perhaps involving more cooperation or, at least, loving competition (DeKoven, 2014).

Besides the role of play and games as part of a shift that necessitates change at every level of human praxis (UNEP, 2021), games have been proposed as tools for a more sustainable world. Relevant concepts in this area include "serious games," or games designed for a purpose beyond entertainment (Djaouti et al., 2011); "game-based learning," or the use of games, whether serious or not, in learning (Perrotta et al., 2013); and "gamification," which is often understood as the integration of game design elements in non-game contexts (Deterding et al., 2011).

While serious games and gamification have often remained conceptually separate (Landers, 2014), recent work has acknowledged that the borders between games and supposed not-games are disappearing (Gekker, 2021) and multiple studies consider gamification, game-based learning, and serious games as expressions of a similar principle; that is, as forms of gameful engagement (Douglas & Brauer, 2021; Koivisto & Hamari, 2019; Krath et al., 2021; Rajanen & Rajanen, 2019). In the same vein, "gamification" has been proposed as the umbrella term to refer to any transformation of activities or systems to afford game-like experiences and support cognitive or behavioral change, by digital or analog means (Hamari, 2019). This includes the way in which serious gaming and game-based learning transform education and training (Hamari, 2019). This is the definition generally used in this dissertation. Based on theoretical foundations suggesting that gamification can elicit experiences of intrinsic need satisfaction, flow, and experiential learning (Krath et al., 2021), it has been used in fields such as education, health, and crowdsourcing, although results have not always been positive (Koivisto & Hamari, 2019).

Thus, it is not surprising that gamification and games have been applied and studied in relation to environmental sustainability and climate change before (see, e.g., Flood et al., 2018; Katsaliaki & Mustafee, 2015; Knol & de Vries, 2011; Liarakou et al., 2012; Madani et al., 2017; Ouariachi et al., 2019; Rajanen & Rajanen, 2019; Reckien & Eisenack, 2013; Stanitsas et al., 2019). In parallel, pro-environmental game design education is on the rise (Fizek et al., 2023) and multiple actors in the games industry have started to organize to bring pro-environmental themes to their products and action to their operations—see, e.g., the Playing For The Planet Alliance and the International Game Developers Association's (IGDA) Climate Special Interest Group, which released a playbook for environmental game design (Whittle et al., 2022). Although the research literature tends to highlight the potential of gamified sustainability and climate change engagement, multiple gaps can be recognized. These include the lack of an up-to-date synthesis of the gamified climate change engagement literature to support both research and practice, the need for more studies (Rajanen & Rajanen, 2019), and the fact that previous analyses of existing games are either obsolete or limited in scope and tend to age fast given that digital games often become inaccessible (Fernández Galeote & Hamari, 2021).

This doctoral dissertation is a response to the lack of consistent knowledge and reporting on the existing literature and games in this area. It also aims to continue developing practice and rigorously analyze player experiences and effects. Here, I express skepticism of the tentative optimism in the public discourse about games' potential to change the world (Gordon, 2023), as I am aware that gameplay is a complex phenomenon that greatly complicates knowing whether climate change games have the desired effect at a broad enough scale (Abraham, 2022). Consequently, I aim to support a (critical) realist view of gamified climate change engagement. This approach recognizes that a gap exists between reality and our knowledge, so a focus on various objects of study and the involvement of diverse methods and disciplines are needed to achieve an adequate (if provisional) understanding of it (Bhaskar, 2008; Bhaskar et al., 2010). Critical realism also posits that scientific inquiry can question existing values if done in careful, pluralistic ways (Archer et al., 2016) and propose alternatives for the future (Bhaskar, 2010). Hence, this dissertation explores gamified climate change engagement from the perspective of the literature, games, and players, uses qualitative and quantitative methods, and proposes research avenues to support a transition towards a more sustainable future.

Gamified climate change engagement includes at least two essential components, both of which remain complex. On the one hand, gamification can be studied from many different angles, including its production, content, use, and outcomes; applied in many forms and contexts, and in combination with methods such as focus groups and debriefing which can help both research (Wibeck & Neset, 2020) and player engagement with the topic (Crookall, 2010). On the other hand, climate change engagement is interdisciplinary, nonlinear, and contextual. Because of this double complexity, the work holistically studies existing literature and games to identify scientific and design gaps and recommendations, engages in design practice, and conducts empirical user research to better understand experiences and effects.

Accordingly, it consists of a literature review, a content analysis focused on game avatars and climate action, an original game design, and a user experience study and two experimental studies involving the game. In terms of the contexts and audiences investigated, the dissertation starts by painting a picture as broad as possible in Publication I, which continues in Publication II by systematically identifying the landscape of digital games depicting climate action, whether serious or for entertainment. From there, Publications III-V define their audience as adults who were in Finland at the time of the research. While the experimental context in Publications IV and V had practical limitations akin to those of educational settings (via a 60-minute time limit), the players were left on their own with the stimuli, so the findings may be representative of single-player interaction with the game in both formal and informal settings. Together, these studies provide a picture of the extant research and practice, as well as the effects of a game designed and developed following identified gaps and best practices.

This dissertation contributes to our societal, scholarly, technological, and artistic understanding and articulation of gamified climate change engagement in several ways. First, it offers a deeper understanding of existing gamified climate change engagement research and practice in the context of scientific production. Second, it provides an account of who players can be and what they can do in digital climate change games. Third, it presents a new design artifact and approach to gamification for climate change engagement. This artifact, *Climate Connected: Outbreak*, aims to transcend existing paradigms such as top-down versus bottom-up and learning-oriented serious games versus direct behavior change-seeking gamification, and engages both traditional digital media and an emergent technology—immersive virtual reality (VR). Fourth, it contributes a rigorous qualitative and quantitative examination of the potential of this approach, including (a) an in-depth qualitative examination of how players interact with the game, expanding our image of who they are and how they act, and (b) quantitative evidence of the game's potential for learning, attitude, and behavior. As a result, the artifact is complemented with design recommendations and best practices learned from the empirical studies conducted. Fifth, the dissertation includes methodological frameworks for analyzing climate change games and exploring serious game user experiences. Finally, this work attempts to bridge fields of inquiry that typically look at different parts of reality, but which can be brought together for a truly interdisciplinary understanding of climate change. For this, it finds its space at the intersection between gamification—with its roots in disciplines such as game studies, media studies, psychology, and human-computer interaction—and climate change engagement—across disciplines such as environmental social science and science communication. At the same time, insights on gamification's role for climate change engagement will be of use for those seeking to involve the public with other grand challenges and wicked problems.

Moving forward, this work provides evidence and potential future avenues for designers, scholars and educators interested in using and creating climate change games, as well as others interested in regulating or promoting their use, such as policymakers and investors. This willingness to be useful to a variety of actors originates from a sustainability argument, too—the fact that we cannot continue to reinvent the wheel amid compound ecological crises, especially because digital games are a part of the problem. While this dissertation does not directly engage with the environmental impacts of video game production, distribution, consumption, and disposal (Abraham, 2022), it recognizes that repeating what has been done is not only wasteful for our time and effort, but also for our limited physical resources. Thus, if gamification for climate change engagement is to become truly sustainable it should integrate relevant evidence in its design and development processes, either extracted from the literature or directly collected from target audiences.

1.1 Research problem and questions

Based on the picture painted above, the main aim of this dissertation is *to understand the current situation of gamified climate change engagement (extant science and designs), to develop a climate change game designed following best practices, and to assess its cognitive, affective, and behavioral engagement effects*. To do so, it compiles five publications, each of which aims to answer one of the research questions below. Together, the answers to the questions help to fulfill the aim of the dissertation.

The scientific understanding of climate change engagement has advanced rapidly in the last two decades (Lorenzoni et al., 2007; Whitmarsh et al., 2015). Currently favored approaches strive for a nuanced comprehension of how lay people tend to relate to science (Irwin & Wynne, 1996) and to climate change (Kollmuss & Agyeman, 2002; Lertzman, 2013). Thus, they oppose simple and problematized methods that focus on providing decontextualized scientific information as if it was necessary and sufficient for engagement (Moser & Dilling, 2011). The emergence of gamification as a tool aligned with our current understanding of engagement and capable of supporting it in a variety of settings (Flood et al., 2018; Rajanen & Rajanen, 2019) warrants a closer observation of its potential, starting with evidence of its past effects. Therefore, the first step in this dissertation aims to offer an up-to-date synthesis of the state of the art focusing on clarifying contexts of use, target audiences, design choices, engagement outcomes—including cognitive, affective, behavioral, and game experience—, and research and evidence quality indicators.

The need to broadly understand gamified climate change engagement is captured in the research question that Publication I, a systematic literature review, addresses:

RQ1: What is the current scientific knowledge of gamified climate change engagement interventions?

This question can be divided into several sub-questions, considering what contexts and audiences these interventions have involved (RQ1.1), what formats and design elements they use (RQ1.2), what their engagement outcomes are (RQ1.3), and what the quality and strength of their results is (RQ1.4).

Parallel to the literature, a corpus of digital games representing, narrating and simulating climate change has been identified in the literature for at least the last decade (Reckien & Eisenack, 2013; Wu & Lee, 2015). More recent analyses of environmental sustainability topics focus either on broader issues than climate change (Katsaliaki & Mustafee, 2015; Knol & de Vries, 2011; Liarakou et al., 2012; Madani et al., 2017; Stanitsas et al., 2019) or restrict their interest to linguistic or geographical contexts other than English or a global scope (Ouariachi, Olvera-Lobo, et al., 2017a, 2017b, 2017c). In particular, climate action and avatars have been largely overlooked in existing studies. This is important because the avatar, or the player's representation and integration in the game world (Apperley & Clemens, 2017), and its actions are crucial elements of engagement (Gee, 2014; Yee & Bailenson, 2007). In a similar way to the literature, the need for a recent and complete study of digital games motivates the second research question, addressed through Publication II:

RQ2: What is the state of the art of games that include climate action?

This question can also be divided into multiple sub-questions considering various aspects of interest, including what avatar identities players are encouraged to adopt (RQ2.1), what climate actions players can take (RQ2.2), what climate issues players are asked to confront (RQ2.3), and what goals players are asked to achieve (RQ2.4).

With a good understanding of the previous research and existing games, including both best practices and gaps, game creation can begin. The creation of a new artifact must be justified, then, by the realization that it can lead to both engagement outcomes and scientific evidence that would not be possible otherwise. In climate change science communication, a salient feature is the framing of the issue (Badullovich et al., 2020). Given the complexity of humans' relationship to climate change, the use of different framings, such as economic and societal benefits of confronting climate change, have seen benefits in a priori contrarian audiences (Bain et al., 2012). A frame susceptible to more research is health, which has the potential to increase forms of climate change engagement (Maibach et al., 2010; Myers et al., 2012; Walker et al., 2018). In addition, the general population seems to lack familiarity with the links between climate change and infectious diseases (Van Wijk et al., 2020), which provides an opportunity for new forms of cognitive, affective and behavioral relationships to climate change causes, impacts, and mitigation and adaptation measures. Furthermore, a health and wellbeing framing was found to be lacking in the existing literature examined in Publication I and in existing games (Fernández Galeote & Hamari, 2021), which acquired special relevance in the context of a global pandemic and the possibility of further health issues exacerbated by climate change and other ecological crises (UNEP, 2021).

In accordance with these observations, a digital game, *Climate Connected: Outbreak*, was developed using the Unity engine (version 2020.3.19f1). Its design followed a process of context exploration, design space development, refinement and making, and assessment and learning (Gaver, 2014). Throughout the process, I engaged with key literature on topics such as climate change engagement, climate change and health (e.g., IPCC, 2021; Knowlton et al., 2021; Pinkerton & Rom, 2021), educational game design (Gee, 2007) and multimedia learning (Mayer, 2005). In addition, the design process involved collaboration with supervisors, colleagues, testers, and experts on topics such as climate change and science communication and education.

The game was then used in a user testing setting. In this case, it was decided that focusing only on a restrictive understanding of the game-based learning experience risks overlooking important aspects of the player's engagement with the game (Aarseth, 2014). Thus, the study described in Publication III adopts an agentic vision of learning (Reeve & Tseng, 2011) and interprets gamification and gaming as a space of tension and negotiation (Deterding, 2014; Gee, 2003; Navarro-Remesal, 2016; Thibault, 2019) to answer the following question:

RQ3: How do players experience and interact with a climate change game designed from and for research?

This question comprises four aspects of interest in the players' relationship with the designed path—continuity (RQ3.1), discontinuity (RQ3.2), divergence (RQ3.3), and engagement with the topic of climate change during and after play (RQ3.4).

Publication I identified a need for more rigorous research designs in gamified climate change engagement, an aspect already highlighted by past studies (Rajanen

& Rajanen, 2019; Soekarjo & Van Oostendorp, 2015). Meanwhile, the study conducted for Publication II identified a lack of immersive VR games. VR's potential for pro-environmental engagement has been touted (Breves & Greussing, 2021) along with the general ecosystem of information and communication technologies (ICT) (Wibeck et al., 2013), but it lacks rigorous examination especially in reference to gameful immersive VR. Therefore, the game described in Publication III was developed further to make it compatible with both screen-based computer systems and immersive VR Quest 2 headsets, and its study extended to include direct action. Then, a lab-based experiment was conducted involving N=105 participants. Focusing on the potential of the climate change game developed for learning, which remains an important component of climate change engagement (Gifford & Nilsson, 2014; Lorenzoni et al., 2007), Publication IV aims to answer the question:

RQ4: What are the learning effects of a climate change game designed from and for research?

This question includes an interest in knowing if the climate change game used can lead to learning (RQ4.1), if the effects differ between a screen-based PC game, an immersive VR game, and a document (RQ4.2), and what may be the relationship between the results and the game's content (RQ4.3).

Based on similar premises as Publication IV, the game's effects on other constructs relevant for climate change engagement, namely climate change attitude, environmental self-efficacy, pro-environmental intention (PEI) and pro-environmental behavior (PEB), were studied and compared between the same conditions. To support these aspects, the game articulates its narrative through a wellbeing frame, makes use of visualizations (Sheppard, 2012) and interactive minigames. It also offers motivational support (Pelletier et al., 1999; Roser-Renouf et al., 2015) and embedded action suggestions representing a variety of possible roles and preferences (Stern, 2000; Wibeck, 2014), as publication II identified a scarcity of flexible and action-oriented citizenship avatar identities. Publication V examines:

RQ5: What are the effects on key engagement indicators of a climate change game designed from and for research?

This final question is operationalized in several hypotheses and research questions involving climate change attitudes, environmental self-efficacy, pro-environmental intention and behavior, interest/enjoyment, and immersion. They can be found in section 4.5. Figure 1 offers an overview of the dissertation.

Figure 1. The doctoral dissertation at a glance including aims, methods, results, and conclusions.

Publication I	**Gamification for climate change engagement: review of corpus and future agenda**
Aim	To understand where, how, and to what effects gamified climate change engagement interventions have been applied.
Methods	A systematic literature review was conducted to analyze a final sample of 64 peer-reviewed empirical scientific publications.
Results	Gamification can have a positive impact in more than one dimension of climate change engagement while providing satisfactory experiences for players, but various population, context, design, outcome, and research quality gaps were identified.
Conclusions	New interventions should consider, for example, that many possible citizen roles beyond the most conventional are neglected; that potentially useful frames such as health and wellbeing are underexplored; that behavior can be directly supported through design; and that more rigorous research is needed.
Publication II	**Avatar Identities and Climate Change Action in Video Games: Analysis of Mitigation and Adaptation Practices**
Aim	To identify what avatar identities, actions, issues and goals can be found in games that include climate action.
Methods	A systematic search and screening of digital games including climate action (N=80) followed by qualitative content analyses of the games and associated paratexts.
Results	Six types of avatar identity were identified based on norms and goals: climate self (N=9), climate citizen (N=4), climate hero (N=21), empowered individual (N=3), authority (N=34), and faction leader (N=9). Mitigation actions feature in 70 games and were classified as lifestyle, public participation, technology, energy, policymaking, nature-based solutions, and violence. Adaptation features in 34 games.
Conclusions	Certain types of identity, especially climate citizens and empowered individuals, are rare in digital games. The action types in those identities closer to that of the average citizen were rather limited, typically including lifestyle actions and public participation. A dearth of immersive virtual reality games and those involving gamified action was also observed.
Publication III	**The Good, the Bad, and the Divergent in Game-based Learning: Player Experiences of a Serious Game for Climate Change Engagement**
Aim	To explore how players experience and interact with a serious game about climate change, including their relationship with the designed path, their possible deviations, and their engagement with the topic.
Methods	A computer game was developed, and a user study conducted (N=12). Notes were taken of gameplay observations and a post-game interview. The data was analyzed using thematic analysis.
Results	The thematic analysis of the data resulted in four themes: continuity includes player progress according to the designer's expectations; discontinuity comprises interruptions and frustrations in said progress; divergence includes departures from the designed path that do not constitute interruptions and frustrations; topic engagement comprises moments of climate change engagement, whether in the game or real-world related.
Conclusions	Some unexpected forms of continuity and discontinuity were found. Players' willingness to diverge suggests that a completely authored game experience Is not possible, and that designers should look beyond equivalences between game design elements and learning outcomes and into agentic, punk and eudaimonic design. The game's didactic approach was limited in supporting pro-environmental intention change.
Publication IV	**From traditional to game-based learning of climate change: A media comparison experiment**
Aim	To examine if a climate change game leads to learning, and if so, how the effects differ between a screen-based PC game, an immersive VR game, and a document.
Methods	An experiment was conducted where participants (N=105) were randomly assigned to one of three groups (text-based control, screen-based computer game and immersive VR game) and completed a 14-question test before and after the treatment.
Results	The intervention had a large positive effect on the learning outcomes, as did each of its conditions. However, There was no significant difference in post-intervention performance between the control and the game groups while controlling for pre-test performance. Game-based and VR learning design recommendations are provided based on the findings.
Conclusions	Story-based single-player games, whether screen-based or in immersive virtual reality, can be as effective as more traditional methods in promoting learning about climate change.
Publication V	**Text- and Game-Based Communication for Climate Change Attitude, Self-Efficacy, and Behavior: A Controlled Experiment**
Aim	To examine if a climate change game influences climate change attitude, environmental self-efficacy, and pro-environmental intention and behavior, and if so, how the effects differ between a screen-based PC game, an immersive VR game, and a document.
Methods	An experiment was conducted where participants (N=105) were randomly assigned to one of three groups (text-based control, screen-based computer game and immersive VR game) and completed climate change attitudes and environmental self-efficacy questionnaires before and after the treatment, as well as interest/enjoyment, immersion, pro-environmental intention and pro-environmental behavior measures after the intervention.
Results	Playing the immersive virtual reality game was found to be significantly more enjoyable than reading the text or playing on the computer. All treatments positively affected participants' climate change attitude and environmental self-efficacy, and supported intentions and behaviors similarly.
Conclusions	Story-based single-player games, whether screen-based or in immersive virtual reality, can be as effective as more traditional methods in promoting climate change attitudes, environmental self-efficacy, pro-environmental intentions and pro-environmental behaviors while being more enjoyable, especially the immersive virtual reality version.

1.2 Dissertation contents and structure

This dissertation includes a systematic literature review on gamified climate change engagement (Publication I), a qualitative analysis of avatar identities and actions in digital climate change games (Publication II), a qualitative exploration of player experiences with a climate change PC game (Publication III), a laboratory experiment providing quantitative evidence of the learning effects of playing the same game on PC and immersive VR as compared to a text-based control condition (Publication IV), and an examination of this experimental design focusing on climate change attitude, environmental self-efficacy, and intention and behavior effects (Publication V). Taken together, the research illuminates the intersection between two complex research spaces, namely gamification and climate change engagement. The dissertation critically examines what already existed in this space in terms of literature (Publication I) and digital games (Publication II) and contributes a new design (Publications III, IV, and V) based on the gaps, opportunities, and best practices identified. In addition, the novel design is examined both qualitatively (Publication III) and quantitatively (Publications IV and V). In short, the literature and content analysis inform the game design and the empirical studies, and all steps combined provide answers and avenues for future research that would not be possible without an analysis of existing research and artifacts, development of a new game-based approach, and analysis of its effects. In this way, the knowledge generated and the creation of a new artifact are not independent; rather, a deeper knowledge allowed to create a new game, which resulted in new insights, which feeds back to what we know as researchers and contributes to building the way forward.

The dissertation that follows is structured in four main sections, including a background, a description of methods, results, and discussion. Section 2 describes the central concepts of this dissertation and its associated publications, including climate change engagement, its cognitive, affective and behavioral aspects, and the scientific understanding of how to support it; gamification and games, including elements of the player experience; and the intersection between the two. Next, Section 3 offers an overview and justification of the methodological approach and the methods used, from the systematic reviewing of literature to qualitative content analysis, user studies, and lab-based experimental research. Section 4 summarizes the research findings, organized in five subsections according to the research topic and question that they address and the publication where they can be found. The discussion of the findings in relation to the dissertation's aim and questions can be found in Section 5, as well as implications, limitations, and future research avenues.

2 BACKGROUND

This work addresses, first and foremost, a sustainability problem. The term "sustainability" can be seen as an abused one, turned into a buzzword for all that is supposedly positive (Morelli, 2013). Even when defined, e.g., as the capacity of a system to survive or persist (Costanza & Patten, 1995), sustainability entails complications regarding what survives, for how long, and when to assess it (Costanza & Patten, 1995). Given the uncertainties intrinsic to forecasting whether a desired system will survive for as long as we want, it has been suggested that policy that aims to support sustainability should be rather precautionary, that is, risk-averse (Costanza & Patten, 1995).

In line with the definition of sustainability, the notion of sustainable development was defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 54), with an emphasis on the needs of the unprivileged. Again, this definition does not clarify a stopping point in the future; that is, what is the last future generation that should meet its needs. Because sustainable development should be potentially infinite but sociotechnical (WCED, 1987) and biophysical (Meadows et al., 1972) resources are not, a precautionary course of action should be taken. This caution has manifested most clearly as calls for the careful deployment of technological innovations, whether their proponents view economic growth as fundamental to sustainability (WCED, 1987) or advocate for radical system change (Schmelzer et al., 2022).

A crucial element in sustainability is environmental sustainability, or "meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them" (Morelli, 2013, p. 6). Taking the climate crisis as the emblematic ecological issue of our time, not only are our most basic needs being jeopardized (Romanello et al., 2022), but life on Earth as a whole (UNEP, 2021). Our current situation is, then, environmentally unsustainable.

Given the severity of climate change impacts on people, both physical (IPCC, 2022a) and psychological (Wray, 2022), it is not surprising that it is considered a top global threat by scientists (IPCC, 2021), the UN (UNEP, 2022b) and citizens around the world (Poushter et al., 2022). Beyond its present impacts, climate change leaves a deep mark in our culture because it cancels our future. The lack of a future leads to a broken present, where much of what we do in our daily lives is robbed of a sustaining context where it will have a consequence and, in short, matter (Collings, 2014). Climate change, then, questions "our very significance and purpose as human beings" (Collings, 2014, p. 12).

Still, climate change is difficult to mitigate for various reasons beyond it requiring coordinated effort. Named a "hyperobject," the more we seem to know about it, the more we realize that we cannot ever fully understand it, leaving a chasm between what climate change truly is and our epistemic apprehension of it (Morton, 2013). Its physical, temporal, and social scale and complexity make it a wicked problem for which definitive solutions that would be accepted by everyone cannot be found (Incropera, 2015). Beyond this, its urgency and the irrational delay in addressing it, its position beyond reach of existing political frameworks, and the ambiguous position of those who can mitigate it but also significantly cause it, turn it into a "super wicked" problem (Levin et al., 2012).

Thus, despite its importance, climate change is far from being under control. The current system is incompatible with a sustainable future, even if future technical innovation is considered (IPCC, 2022b). Existing greenhouse gas emission targets and public policies are incompatible with keeping the planet's warming under 1.5 or even 2º C (UNEP, 2022a; United Nations Framework Convention on Climate Change secretariat [UNFCCC], 2022) as decision-making largely depends on market values (IPBES, 2022) and climate talks are influenced by vested interests and power asymmetries (Stoddard et al., 2021). In contrast, the situation requires a change of paradigm where human well-being is recognized (Boehm et al., 2022; Stoddard et al., 2021; UNEP, 2021) and secured through global solidarity (IPCC, 2022b).

This shift towards an effective mitigation of and adaptation to climate change involves, and thus needs to engage, virtually every individual and collective. Positive change depends on widespread adoption of new practices (Lenton et al., 2022) and a reevaluation and expansion of what citizens can do (Wibeck, 2014), including opportunities to make decisions beyond the private sphere (Paas, 2016). Through more citizen involvement, mitigation and adaptation decisions will not only be led from the top, but publicly demanded. In this way, we arrive at the concept of climate change engagement.

2.1 Climate change engagement

This dissertation adopts the definition of climate change engagement proposed by Lorenzoni and colleagues: "a personal state of connection with the issue of climate change ... concurrently comprising cognitive, affective and behavioural aspects" (Lorenzoni et al., 2007, p. 446). According to this conceptualization, complete engagement is neither based on awareness alone, nor it hinges exclusively on public participation, but it includes and transcends them, since it requires care for the issue and motivation to act (Lorenzoni et al., 2007).

Despite existing awareness, concern and action, promoting and supporting climate change engagement is difficult. Its cognitive, affective and behavioral components, which will be introduced next, are interrelated in complex and nonlinear ways (Whitmarsh et al., 2015). In addition, our relationship with climate change is mediated by pervasive and persistent socioeconomic, physical, and personal elements (Lorenzoni et al., 2007; Whitmarsh et al., 2015; J. Wolf & Moser, 2011). Hence, traditional attempts to promote public understanding of science based on providing information in a top-down and one-size-fits-all manner, the so-called information deficit model, have had limited success in promoting engagement (Kollmuss & Agyeman, 2002; Lorenzoni et al., 2007; Moser & Dilling, 2011; Suldovsky, 2017; Whitmarsh et al., 2015).

The first component of climate change engagement, knowledge, remains important even if it is insufficient for pro-environmental action (Gifford & Nilsson, 2014) and does not always precede or anticipate action or affect (Kollmuss & Agyeman, 2002; Lorenzoni et al., 2007; Whitmarsh et al., 2015). Even though someone can be engaged in pro-environmental action without significant cognitive involvement and because of some other form of incentive, underpinning mitigation actions with climate change awareness may be beneficial for meaningful continuance beyond motivations such as financial gains or social pressure (Lorenzoni et al., 2007).

Knowledge is not a monolithic concept. People may have different levels of understanding, between isolated facts to systems understanding, and varying degrees of familiarity with climate change causes, impacts, and proposed mitigation and adaptation measures and strategies (Kaiser & Fuhrer, 2003; Kollmuss & Agyeman, 2002). Ecological understanding also exists in multiple tiers between full denialism and full comprehension, depending on how much we accept the severity of our current circumstance and the dimensions of its consequences—and therefore, the most adequate path forward, which can range from techno-solutionism to radical social change (Catton, 1982). To complicate matters further, when people are confronted with climate change information multiple factors come into play, including beliefs, values, and attitudes as well as political, socioeconomic, and cultural factors (Gifford & Nilsson, 2014; Lorenzoni et al., 2007; Whitmarsh et al., 2015). These complex interactions can result in noticeable attentional and perceptual biases (Luo & Zhao, 2021).

The second component, affect, also plays an important role in climate change engagement. Our emotional relationship with climate change has been studied by scholars in the psychosocial tradition, who have problematized simple narratives of denial (Norgaard, 2011) and consider "affect, unconscious (or nonconscious) defense mechanisms, cognitive dissonance, anxiety, guilt, shame" (Lertzman, 2019, p. 28). Recently, researchers have engaged in extensive work to map out the emotional landscape of climate change, including negative emotions but also positive ones such as care, empowerment, and hope (Pihkala, 2022), children's coping strategies (Ojala, 2012), and climate anxiety or grief (Wray, 2022).

Finally, the third component of engagement, behavior, also shows remarkable variety. For example, climate change engagement comprises private and public actions (Whitmarsh et al., 2015) in milieus such as the street, the supermarket, and the workplace (Stern, 2000). It can also manifest in at least two ways, through mitigating action—limiting greenhouse gas emissions or strengthening sinks—and adaptation—preparing for and adjusting to climate change (IPCC, 2021).

Between cognition, affect, and behavior, a constellation of constructs has been considered important in people's engagement with climate change. Some variables used in pro-environmental behavior models include consequence awareness, responsibility, personal norms (Schwartz, 1977), values, threat beliefs and possibility to engage in restorative action (Stern et al., 1999), personality traits, sociocultural factors, and other circumstances (Kollmuss & Agyeman, 2002).

From the myriad concepts related to climate change engagement that combine and transcend aspects of cognition, affect, and behavior, Publication V examines climate change attitude and environmental self-efficacy. Someone's attitude towards an issue or activity includes their relevant beliefs, affect, and intentions (Schultz et al., 2005). Interventions to improve climate change attitudes tend to have a small positive effect (Rode et al., 2021). Self-efficacy may be understood as personal confidence in one's capacity to overcome barriers to behavior (Moeller & Stahlmann, 2019) and it can be developed through direct experience, observation, social persuasion, and the induction of different psychophysiological states (Lehikko, 2021). Combatting the causes of amotivation towards pro-environmental action can be a valuable avenue to promote self-efficacy (Pelletier et al., 1999). Interventions that transmit information have increased efficacy beliefs (Geiger et al., 2017), and both immersive VR and text can increase capacity beliefs towards the environment (Ahn et al., 2014). Attitude and self-efficacy are often seen as possible precursors to people's pro-environmental intentions (PEI) and pro-environmental behaviors (PEB) (e.g., Ajzen, 1991; Casaló & Escario, 2018; Klöckner, 2013). In turn, PEI influences PEB (Ajzen, 1991; Ajzen & Fishbein, 1980).

2.2 Approaches to climate change engagement

Given the complexity of climate change engagement, and the limitations of the information deficit model, researchers have proposed more nuanced methods for promoting and supporting it. In general, these initiatives shift the focus from public understanding to public engagement, which involves a more horizontal form of communication or at least considers people's personal and situated understanding of science (Moser, 2010; Wibeck, 2014; J. Wolf & Moser, 2011). Various authors have proposed adopting radical listening methods to acknowledge the subconscious elements of climate change engagement, including anxiety and ambivalence (Lertzman, 2019), as well as interventions that consider the roles of communities beyond the individual (see Rajanen, 2021).

One set of proposals refers to messaging strategies, such as frames that contextualize climate change as a relevant issue for specific audiences (Badullovich et al., 2020). One example is highlighting the social and economic benefits of mitigating climate change (Bain et al., 2012) or its impacts in terms of wellbeing and health (Maibach et al., 2010; Myers et al., 2012; Walker et al., 2018). Persuasive messaging could focus on deep engagement techniques, such as perspective-taking, to connect messages with the audience's values; highlighting personal risks, morality and systems thinking to restructure mental models; and leveraging social norms to influence personal norms (Goldberg et al., 2020). Effective interventions can also highlight and promote engaging emotions and behaviors (Brosch, 2021; Schneider et al., 2021).

Different media also have an important role in climate change engagement (Rajanen, 2021). Scholars have proposed using digital visualization techniques (Moser, 2010; Sheppard, 2012; Wibeck et al., 2013), which comprise immersive VR environments such as those experienced through head-mounted displays (HMD). In particular, the use of interactive visualizations presents cognitive advantages—it allows for using cognitive capacity efficiently, facilitates information search and pattern recognition, simplifies complexity, and allows the manipulation of data (Thomas & Cook, 2005). Broadly, simulations aid understanding, especially those involving direct manipulation (Black, 2010). Particularly, immersive VR affords vivid representations of sensory information and more elaborate bodily movements than, e.g., desktop environments (Li et al., 2020). Methods such as VR can, in addition, elicit emotional states and a sense of presence (Pellas et al., 2020) which is especially relevant for a topic that is often seen as far away and nebulous (Monroe et al., 2019; Sheppard, 2012). VR has been effective in learning about environmental topics (Ou et al., 2021) and climate change (Markowitz et al., 2018), but it has disadvantages too when compared to other media. It may be less effective in promoting learning than other presentations of content (Barreda-Ángeles et al., 2021; Makransky et al., 2019; Moreno & Mayer, 2002; Parong & Mayer, 2018) due to a higher cognitive load or its exploratory affordances, which distract from narration. The low resolution of some HMDs may also result in blurry text and tiredness (Knaack et al., 2019).

Yet, the potential of active and visual methods has led to considering games and gamification's affordances as useful to promote climate change engagement. More research in this field is especially valuable considering the many contexts, audiences, and possible targeted outcomes relevant to climate change engagement, the diversity of outcomes observed in the existing literature, and the limited amount of research in the nascent field of interactive digital media—and more so, immersive VR (Breves & Greussing, 2021).

2.3 Gamification and games

Although games are notoriously difficult to define (Stenros, 2022), a commonly used definition considers games to be "system[s] in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome." (Salen Tekinbas & Zimmerman, 2003, p. 81). Following this basic structure, digital serious games, or those with a purpose beyond entertainment, have existed since the 1950s, with the advent of the digital computer (Djaouti et al., 2011). Meanwhile, game-based learning refers to using game systems as resources in learning (Perrotta et al., 2013), which need not be digital (Plass et al., 2015) nor designed with a motive other than entertainment (Perrotta et al., 2013). Eventually, the second decade of the 21st century saw the emergence of gamification as the use of game design elements in non-game contexts (Deterding et al., 2011). The term would eventually be used to describe, more broadly, the widespread adoption of gameful systems and practices not only for entertainment, but also to influence cognition and behavior (Hamari, 2019). Particularly, intentional gamification uses game design techniques to transform activities so that they afford game-like experiences for utilitarian results (Hamari, 2019). This conceptualization of gamification, which is adopted in this dissertation, considers any form of gameful engagement, including serious games and game-based learning, as part of the same overall phenomenon. Consequently, numerous studies, including Publications I and II in this dissertation, have included game artifacts alongside other forms of gamification (Douglas & Brauer, 2021; Koivisto & Hamari, 2019; Krath et al., 2021; Rajanen & Rajanen, 2019).

The use of gamification has been justified through at least three arguments. The first one is pragmatic—games are popular, with over three billion players globally (Wijman, 2020), and therefore a language that many find both familiar and attractive. A second argument is tied to a popular theory underpinning gamification—experiential learning (Krath et al., 2021). When learning outcomes are sought, the argument posits that concrete experiences—active, situated, risky, related to real challenges, and critically reflected upon (Morris, 2020)—such as those afforded by games and gamification are good ways to learn. An important third argument is based on other theoretical bases of gamification—self-determination theory and flow theory, both of which highlight psychological well-being (Krath et al., 2021). It has been argued that gamification can motivate players by supporting the three basic psychological needs of competence, autonomy, and relatedness (Ryan et al., 2006; Xi & Hamari, 2019) and afford flow experiences (Cowley et al., 2008; Hamari & Koivisto, 2014).

The player experience typically includes aspects such as enjoyment, or the feeling that accompanies a pleasurable experience (Cairns et al., 2014). Even in education, games are typically more enjoyable than other methods (Arici, 2008; Lieberoth, 2015; McLaren et al., 2017), as is immersive VR (Makransky et al., 2021; Makransky & Mayer, 2022; Pellas et al., 2020; Reer et al., 2022). This may be at least partially attributed to the fact that new, surprising, and puzzling experiences tend to elicit curiosity (Berlyne, 1954), including the "novelty effect" sometimes associated with gamification which can lead to effectiveness predominantly or only in the short-term (Hamari et al., 2014). Another concept connected with positive game experiences is immersion, or attentional and emotional involvement in an activity (Cairns et al., 2014). Immersion may happen through challenges, imagination, and sensory aspects of a game experience (Ermi & Mäyrä, 2007). Some aspects of immersion, such as the feeling of being present in a virtual environment, can be heightened through a higher degree of technological immersiveness (Cummings & Bailenson, 2016).

One of the most obvious elements influencing the player experience in games, and one that is extensively discussed in Publication II, is the avatar. This concept has been given multiple similar meanings, including the element mediating player agency, their visual manifestation in the game world, their character, and their virtual body (Juul & Klevjer, 2016). This dissertation understands the avatar as a technique that interfaces between the machine, the player's body, and the on-screen actions by representing the player and integrating them into the virtual world (Apperley & Clemens, 2017), whether the representation includes a virtual body or not. The avatar, then, is the artifact through which players learn how to exist in the game world and represents their primary identity cue (Yee & Bailenson, 2007) suggesting what their role is. The player-avatar relationship may impact attitudes and behavior (Ratan et al., 2020; Yee et al., 2009) and so avatars have been used to influence, among other targets, environmental attitude (Ahn et al., 2016).

Hence, the avatar's identity, or the one that players are encouraged to adopt by design in a game, is one aspect of interest in gamification. It has been proposed that a new identity, the ludic subject, emerges because of play (Vella, 2016), or that the mix between the player and the game's character configure a so-called projective identity separate from both (Gee, 2014). Even so, the avatar itself, even independently of player input, can be said to have an identity (Gee, 2014) based on their goals and the norms that influence how their objectives should be achieved (Gee, 2008). This identity frames player expectations and thus decisively influences the play experience (Sharp, 2014). Accordingly, since behavior is a main aspect of role identities even in the real world (Kaplan & Garner, 2017), in-game actions are directly connected with avatar identity roles. Such an analysis of avatar identity is also possible because most of them, unlike real people, are rather straightforward and unified (Vella & Cielecka, 2021).

But in any kind of game system, the player experience is more complex than embracing a prescribed role, with its goals, norms, and set of actions. Game designers seek to facilitate a particular gameplay experience, typically resulting in a state of flow (Fullerton, 2014), while gamification adds to this goal the achievement of cognitive or behavioral outcomes, as explained above (Hamari, 2019). Because of this, utilitarian game design frameworks focus on the detailed authoring of the player experience (Pereira de Aguiar et al., 2018) and supporting outcomes such as learning (Arnab et al., 2015; Carvalho et al., 2015; Connolly et al., 2008). However, nothing guarantees that players will be having a particular experience of continuity with the game such as the one that flow represents, nor they will necessarily be interested (only) in learning. Rather, they may retain their agency in learning (Gee, 2003) and even try to engage with games in unexpected and playfully divergent ways (Deterding, 2014). This can lead to friction with the game system and to a negative experience, especially if serious play is somewhat forced (Heeter et al., 2011).

Thus, designing to support player autonomy, instead of focusing only on constraining it for a predefined experience and outcomes, can be not only desirable, but realistic. For example, designers can ensure that players can make meaningful choices (Salen Tekinbas & Zimmerman, 2003), explore, restructure content, and approach problems differently according to their preferences (Deen, 2015). They may at least understand the limits at their disposal to manage player freedom, including hard constraints but also suggestions (Navarro-Remesal, 2016). Drawing on the educational concept of agentic engagement (Reeve & Tseng, 2011), gamification can support player-led customization, initiative, and creativity, leading to eudaimonic experiences (Deterding, 2014) rather than attempting to control what players do, think and feel (Thibault & Hamari, 2021). Given the intricacies of climate change engagement, these player-centric perspectives acquire even more relevance.

2.4 Gamification and games for climate change engagement

Gamification has been said to include multiple elements to support cognitive, affective, behavioral, and sociocultural engagement, including game mechanics, informational content, visual aesthetics, stories, and music (Plass et al., 2015). As said above, gamification offers affordances that can be particularly valuable for climate change engagement, including visual communication of climate change (Sheppard, 2012), system and social interaction, cognitive and emotional engagement through narratives and other mechanisms (Hemenover & Bowman, 2018), adaptation to player performance, and incentives to motivate players (Plass et al., 2015).

The use of gamification in relation to environmental sustainability and climate change is not new. Serious games for climate change have existed since at least the 1980s (Robinson & Ausubel, 1983), with the amount of games (Fernández Galeote & Hamari, 2021; Reckien & Eisenack, 2013) and studies (Hallinger et al., 2020) having grown since the 2010s (for research relevant to climate change and games see, e.g., Abraham, 2018; Abraham & Jayemanne, 2017; Chang, 2019; Flood et al., 2018; Katsaliaki & Mustafee, 2015; Kelly & Nardi, 2014; Knol & de Vries, 2011; Liarakou et al., 2012; Madani et al., 2017; Makai, n.d.; Op de Beke, 2021; Ouariachi et al., 2019; Rajanen & Rajanen, 2019; Reckien & Eisenack, 2013; Stanitsas et al., 2019; Wu & Lee, 2015). Existing games and gameful interventions have targeted a variety of engagement goals, including cognitive, affective, and behavioral. They have led to learning and desired behaviors when high trust between stakeholders, competent facilitation, and debriefing and evaluation existed (Flood et al., 2018). Based mostly on qualitative methods and/or case study data, they have generally succeeded in engaging players with climate change (Rajanen & Rajanen, 2019).

Recent games described in the literature include novel designs for climate-relevant science communication (Burch et al., 2016; Moulder et al., 2018), biodiversity issues (Blunt et al., 2020; Newsome, 2020), energy (Banerjee et al., 2016; Johnson et al., 2017), mobility (Gabrielli et al., 2013), production (Rogers et al., 2018), and climate mitigation and adaptation action (Chan & Leung, 2020). Besides more traditional game designs, some initiatives include playful interaction methods (Jennett et al., 2016), social features (Lee et al., 2013; Marconi et al., 2018; Meyers & Nathan, 2016), and solar-powered wearables (Chisalita et al., 2022). Other work includes advances in environmental game design education (Fizek et al., 2023; Troiano et al., 2020) and guidelines for game designers willing to represent environmental or climate change-related topics (Diniz dos Santos et al., 2019; Fabricatore et al., 2014; Ouariachi et al., 2019; Whittle et al., 2022).

Empirical research has found that, compared to other media, games can support pro-environmental attitudes more effectively (Janakiraman et al., 2018) and raise more interest (Nussbaum et al., 2015). The use of immersive VR, whether interactive or not, has also been associated with pro-environmental attitude gains (Ahn et al., 2016; Breves & Greussing, 2021; Markowitz et al., 2018). Closer to self-efficacy, immersive VR has improved internal environmental locus of control more than exposure to video and text (Ahn et al., 2014). Previous research has generally found that more immersive or interactive conditions lead to increased gains in PEI and PEB when compared to other conditions (Ahn et al., 2014, 2015; Oh et al., 2020).

Yet, multiple gaps limit our understanding of gamification's potential for climate change engagement, especially in terms of why certain designs are more effective than others in supporting, for example, behavior change (Douglas & Brauer, 2021). One important gap is the lack of a current review of the gamified climate change engagement literature comprising contexts of use, target audiences, design choices, engagement outcomes, and methods of scientific measurement and analysis used. In general, though, more studies are needed in the areas of climate change (Rajanen & Rajanen, 2019) and environmental sustainability, especially those using robust empirical designs (Hallinger et al., 2020) and comparing games to other treatments offering similar information (Soekarjo & Van Oostendorp, 2015). Where comparisons exist, the advantage of using games for attitude change and learning may be non-significant (Ouariachi et al., 2018; Soekarjo & Van Oostendorp, 2015) or limited to a more positive experience and learning aspects such as retention (Pfirman et al., 2021). Similarly, the empirical evidence of immersive environmental persuasion's advantages over other options is limited and focuses on non-interactive designs such as 360º videos (Breves & Greussing, 2021). Therefore, our knowledge remains fragmented and with little evidence comparing games and/or immersive technologies with other media.

In terms of format, immersive VR is rare in game-based climate change engagement (Fernández Galeote & Hamari, 2021), which is natural given the relative newness of consumer devices such as the Quest headsets and their lack of widespread adoption when compared to other digital technologies. In fact, the durability of our knowledge of existing climate change games is contingent on them remaining available, which is not always the case given their tendency to become inaccessible over time (Fernández Galeote & Hamari, 2021), and on the pool of games remaining stable, which is not to be expected based on previous research (e.g., Reckien & Eisenack, 2013; Stanitsas et al., 2019).

According to the ideas presented in this section, this dissertation focuses on addressing various identified gaps—integrating the existing gamified climate change engagement literature (Publication I), exploring the extant climate change games space to uncover avatar identities and their potential for engagement (Publication II), proposing a deeper consideration of the player experience in climate change games (Publication III), and combining gamification, rigorous research designs, underexplored message frames, and immersive VR to assess the climate change engagement potential of games compared to other media (Publications IV and V).

3 METHODS

This project is articulated into four phases—understanding the existing research on gamified climate change engagement (RQ1), mapping out the landscape of existing climate action games (RQ2), exploring the player experience of a new digital game (RQ3), and using an improved version of the game to experimentally examine engagement constructs ranging from learning (RQ4) to attitudinal and behavioral indicators (RQ5).

In phase one, a systematic literature review (Okoli, 2015; Petticrew & Roberts, 2008) examines the contexts and audiences (RQ1.1), designs (RQ1.2), research outcomes (RQ1.3) and processes (RQ1.4) of gamified climate change engagement interventions with the goal of providing a research agenda. In phase two, the second study collects qualitative and quantitative data from digital climate change games and analyzes them through various qualitative content analysis techniques (Kuckartz, 2014) to provide a categorization of avatar identity types (RQ2.1), actions (RQ2.2), issues (RQ2.3) and goals (RQ2.4). In phase three, Publication III applies thematic analysis (Ritchie et al., 2013) to data collected from 12 players of a *Climate Connected: Outbreak* beta to provide a detailed account of their serious gameplay experience, including moments of continuity (RQ3.1), discontinuity (RQ3.2), divergence (RQ3.3), and climate change engagement (RQ3.4). Finally, phase four studies effects of *Climate Connected: Outbreak* in Publications IV and V. These employ a controlled experiment with random assignment of participants (N=105) to one of three groups: a digital game in immersive VR, the same game on PC, and a text-based control. The results are based on self-reported quantitative data collected through surveys. Publication IV studies learning (RQ4.1) in relation to a control condition (RQ4.2) and to the game's design (RQ4.3). Publication V examines other key engagement indicators (RQ5), including attitude, self-efficacy, and behavior.

The four phases are connected so that earlier ones inform the next ones. The literature review undertaken for phase one contributed to phase two by providing a list of games used in research which were then screened and analyzed as part of the sample. The game analysis in phase two provided knowledge on existing games and their characteristics which, together with research and design insights from phase one, decisively shaped the game design and development choices for *Climate*

Connected: Outbreak. In phase three, a beta version of the game was used to understand player experiences, which resulted in significant changes to the final version used in phase four. By revealing aspects of interest, phases one and two also influenced aspects of the research design in phases three and four, such as what aspects of engagement to measure, as did the game's design directly (e.g., the questionnaire used in Publication IV was directly influenced by the game's content).

The variety of study objects and methods chosen was judged as commensurate with the multifaceted reality of climate change, its engagement, and gamification. This approach is aligned with critical realism, this work's scientific-philosophical anchor. As meta-theories do, critical realism provides a philosophically informed understanding of what science, including social science, is, so that empirical research can be conceptualized accordingly (Archer et al., 2016). Most importantly, critical realism aims to avoid the "epistemic fallacy," i.e., the belief that what we know is what exists, by differentiating between ontology, or the elements of reality, and epistemology, or what we know of it (Bhaskar, 2008). Accordingly, it posits that science consists of two dimensions—the intransitive one, which refers to what exists independently of humans and scientific inquiry, and the transitive, or the production of scientific knowledge (Bhaskar, 2008).

Critical realism considers that reality consists of three domains, each containing the one(s) following it. These are the real, or the structures of reality including the potential and the manifest; the actual, or the events that occur; and the empirical, or the events that are perceived (Bhaskar, 2010). Thus, causal laws refer to tendencies, not only conjunction of events (Bhaskar, 2008). The social world also contains social structures with emergent powers, which certain conditions activate through generative mechanisms leading to event patterns (Tsoukas, 1989, as cited in Avenier & Thomas, 2015).

Furthermore, critical realism is said to consist of a "holy trinity," namely, ontological realism and epistemological relativism, as described, and judgmental rationality, or the existence of explanatory critiques with more power than others (Bhaskar, 2010). Because of ontological realism, researchers applying a critical realist perspective assume that causation should be approached critically, minding the possible gaps between our observations and the complex structures that cause observed events (Archer et al., 2016). In a similar way, epistemic relativism suggests that reality can only be grasped in ways in which a broad scope and deep insight are generally at odds due to our limited capability to observe and interpret reality (Archer et al., 2016). Despite the limitations of social scientific inquiry, judgmental rationality acknowledges that the social sciences can make relatively valid claims of reality, even if imperfect and provisional (Archer et al., 2016). A fourth element, cautious ethical naturalism, is particularly relevant to the social sciences, as it establishes that values can be questioned, but their criticism should be prudent and consider diverse points of view (Archer et al., 2016).

How should one conduct social science from a critical realist perspective? Because invariant empirical regularities do not occur outside of closed contexts, methods of artificial generation (e.g., experiments) are the empirical way to access (intransitive) causal laws that live beyond what we can observe, and which should be conceptualized as separate from us and the patterns of events that the experimenter causes and these mechanisms generate (Bhaskar, 2010). Then, to propose laws or intransitive mechanisms that we assume to exist, we require theories or explanatory models that describe how they cause events (Bhaskar, 2008).

However, distinguishing between the natural and the social sphere, Bhaskar (2014) considers that natural laws are causally intransitive, while in the social world causality is additionally complicated by interdependence, mutability, and the fact that society and science change with and relate to each other. In other words, social structures predate human agency and action, but are actualized and transformed through them (Bhaskar, 2010). Human agency exists at multiple levels, including the psychological, biographical, micro (studied through ethnomethodologies), meso (relationships between functional roles), macro, mega, and planetary or cosmological (Bhaskar, 2010). In addition, social life exists in a four-planar structure, where social events may involve material transactions with nature, interactions between people, social structure, and embodied personality (Bhaskar, 2010), including mental and emotional experiences. These levels and planes provide a rich and multi-layered framework to study the complexity of social reality.

Particularities of the social world notwithstanding, the goal of the social scientific process remains to identify the general mechanisms that cause events, and what activates them (Avenier & Thomas, 2015). Reliable research should demonstrate the cognitive path followed from data to findings; explain observed similarities and differences plausibly; accurately explain the world through through large, precise, and varied relevant data; generalize via abstraction, from surface observations to deep causes; and refine theories through qualitative methods and test them through quantitative work (Avenier & Thomas, 2015).

Because social phenomena manifest fully only in open systems and not in closed systems (e.g., a laboratory), and thus have multiple causal structures (Bhaskar, 2010) that cannot be completely identified or exactly replicated, social theories should be explanatory rather than predictive (Bhaskar, 2014), aiming to convincingly demonstrate why and how something occurs rather than anticipating future events, when at least some relevant social conditions have likely changed.

Climate change needs interdisciplinary research guided by critical realist perspectives (Bhaskar et al., 2010). Complex and multi-level aspects of reality require diverse methods to build systematic knowledge (Rousseau et al., 2008), with an object's nature determining the form of its inquiry (Bhaskar, 2014). Such interdisciplinary work requires both the use of insights from multiple fields (transdisciplinarity) and their empathetic understanding beyond the scientist's own field (cross-disciplinarity) (Bhaskar, 2010). For example, initiatives that seek to educate for responding to climate change are seen as crossing over multiple domains (Cornell & Parker, 2010). Furthermore, scholars are given a role beyond explaining reality; that is, envisioning possible futures for humanity grounded in what exists (Bhaskar, 2010) and thus manifesting a form of concrete utopianism informing an optimism of the will and a realism of the intellect (Frank, 2010).

This work adopts the critical realist perspective in several ways. First, it embraces epistemic humility—the research acknowledges that its findings and conclusions, however rigorously supported, incorporate a degree of incompletion and provisionality, and cannot be equated with the reality that they describe. In agreement with this perspective, and to facilitate the acquisition of useful insights about a complex issue, it remains closer to questions of "what is it [...] that works, for whom, in what circumstances, in what respects and why?" (Paré et al., 2015, p. 189), rather than aiming to answer whether gamification for climate change engagement works. This perspective is adequate for gamification studies, since effects depend largely on the context and the user (Hamari et al., 2014).

Second, multiple methods and extensive collection of data are used to probe the mechanisms of reality and our judgments about it (Rousseau et al., 2008). The research questions reflect an interest in achieving an understanding that is as systematic and all-encompassing as possible in terms of what literature and games exist (RQ1 and RQ2) while being rich and complex (RQ3) and exact and multi-dimensional (RQ4 and RQ5) in terms of player experiences and their climate change engagement. As said above, both qualitative and quantitative evidence are considered valid to answer such questions and triangulation is favored over advocacy of single data types and methods (Rousseau et al., 2008). In a literature review, for example, any type of study can contribute to understanding when and why a mechanism (say, gamification as a distinct kind of artifact and human practice, a game format, or a game element) has an effect (Rousseau et al., 2008). Furthermore, it is acknowledged that multiple theories can be integrated to explain the same phenomenon without contradiction (Rousseau et al., 2008). Therefore, this dissertation incorporates different perspectives relevant to gamification experiences and outcomes, from player-centric, agentic and eudaimonic forms of learning engagement in Publication III to more design-centric and persuasive ones in Publications IV and V.

Third, nuanced explanations of processes and inferences attempt to detail the possible causes and structures behind the observed phenomena. This includes a focus on contexts, audiences, designs, and the scientific process behind outcomes (Publication I), a classification of avatar identities and actions beyond the generic concept of "climate change game" (Publication II), and the application of a game design with defined characteristics, in a particular context, for a particular audience, in a controlled environment, and examining particular outcomes (Publications III-V). All studies are underpinned by gamification and climate change engagement theoretical concepts and evidence.

Fourth, the work done considers the complexity of its objects of study. Though it does not primarily engage with gameplay as (dependent on) environmentally problematic material artifacts (see, e.g., Abraham, 2022; Huntemann & Aslinger, 2013; Mills et al., 2019), its examination of engagement is related to the ways in which people relate to nature, others, their social structures, and their own identity. The empirical research conducted focuses on the psychological and biographical levels, but the examination of artifacts made by, targeted at, and experienced by collectives—literature and games—points towards higher levels of human agency. By involving this complexity of human action and social events, climate change engagement is conceptualized as a complex and multifaceted state of connection with climate change (Lorenzoni et al., 2007) rather than forms of thinking, feeling, or doing in isolation. Climate change engagement is not only internally complex as a construct—it is also outerly complex, as it is shaped by its context, and both climate change and its engagement are co-complex as they influence each other's progression (Bhaskar, 2010). As a social phenomenon, gamified climate change engagement is a component of the climate change engagement element, and dependent on the evolution of climate change and our perceptions of it.

Lastly, this dissertation aims to be a step in the direction of a possible sustainable future (Bhaskar, 2010; Frank, 2010) in two ways. One, by highlighting the possible role of games and gamification in bringing such future closer. And two, by noting that playful engagement and desirable outcomes for society and life on Earth are a part of such a desirable future. Hence, the possible role of gamification in building this future becomes a matter of scientific examination.

As a summary, this dissertation sees science as a process-in-motion (Bhaskar, 2008) in which:

1. A new level of reality, namely gamification for climate change engagement, is identified and described (Publications I and II).
2. Possible explanations relative to this new level of reality's nature and effects are built (discussion in Publications I and II and subsequent work) and tested through reasoning, new artifacts, and empirical methods (Publications III, IV, and V).
3. New interpretations for the previously identified explanations are built (results and discussion in Publications III, IV, and V) and their testing is proposed, as this doctoral dissertation compiles the work done and suggests possible future avenues.

3.1 Positionality and ethical statements

Complementing the meta-theoretical perspective described above, this inquiry benefits from a positionality statement. If what we observe is not always what occurs, and this is not the same as the mechanisms that cause what occurs and what could occur, the researcher's perspective may affect their interpretation of reality. I, as a researcher, am not neutral. As a human who experiences nature, social institutions, others, and my own internal life, I can identify at least two categorical aspects that could influence how I collect and interpret information, namely, my attitude towards climate change and gamification and my relevant biographical experience.

First, I am deeply concerned about climate change and other ecological crises, and consider that games are a potentially valuable addition to the mitigation and adaptation toolkit, especially given the generally positive findings of Publication I. But even before, the purpose of the research endeavor itself, by attempting to contribute to addressing a challenge and promote planetary wellbeing, is not neutral—I aim to understand the world, but also to improve it. Yet, for this positive predisposition to not become a bias that endangers the scientific process, I aimed to keep a skeptical and critical (realist) attitude in my work.

Second, I have relevant experience as a game developer, journalist, and player. At the time of starting the work presented in this dissertation, I had around five years of professional experience designing and developing games and gamification. This provides the advantage of an intimate knowledge of how games work under the hood and an intuitive analytical understanding of their components when experienced as a player. I am also an undergraduate in Journalism with experience in game analysis, which can be useful when analyzing games, persuasive messaging, and the experiences they afford. In addition, I have regularly played multiple game genres for over two decades, which complements my knowledge as a professional and analyst. Yet, these informed perspectives may breed overconfidence. In addition, I have preferences for certain mechanics, stories, and visual aesthetics as a player. Thus, for every finding, tangible examples were sought rather than general impressions or intuitions, and I tried to collect and analyze data with a similar degree of effort whether I was enjoying it or not.

Finally, the research ethics and good practices observed during the completion of this dissertation and its constituting articles were based on the guidelines of the Finnish National Board on Research Integrity (Finnish National Board on Research Integrity [TENK], 2019). Based on these guidelines, it was considered that the empirical research conducted as part of this dissertation did not require an ethical review for the following reasons:

1. Participation in the research does not deviate from the principle of informed consent. Explicit and informed consent was collected and the right to withdraw was communicated to the participants, all of whom were adults.

2. The research did not intervene in the physical integrity of the participants. None of the conditions involved measuring physical condition, taking physiological samples, ingesting products, or restricted physical freedom to stop at any given point.

3. The research was not considered to expose participants to exceptionally strong stimuli. The content depicted in the game was not dissimilar to the information on the climate crisis that can be found in daily life, and it did not recreate forms of direct violence. Because the nature of the content itself was not exceptionally strong and the graphics are cartoon-like, using immersive VR was not considered an added risk.

4. The research was not considered to risk causing mental harm beyond the limits of normal daily life. Possible emotional experiences or mental strain from reading the text or playing the game were considered akin to what can be experienced by, e.g., watching a documentary or reading a news story. The use of immersive VR was again considered to be in line with daily life experiences, especially given that the graphics in the game are cartoon-like rather than realistic.

5. The research did not pose a threat to the researchers', the participants', or others' safety. Participants were not asked to share data that could put them at risk of external retaliation. All participant data were nonetheless anonymized.

The Finnish and European data protection regulations were also followed, with a Data Protection Impact Assessment (DPIA) having been drafted with and approved by Tampere University's Data Protection Officer (DPO).

The following sections detail the methods used in the studies that constitute this dissertation. Table 1 offers a summary.

Table 1. Methods used in this dissertation.

Method	Description	Operationalization	Pub.
Systematic literature review	A literature review that attempts to "identify, appraise and synthesize all relevant studies … to answer a particular question" (Petticrew & Roberts, 2008, p. 9)	As conventionally used (Okoli, 2015) to analyze a final sample of 64 research outputs	I
		Adapted to digital game search and screening, resulting in 80 games selected	II
Qualitative data analysis	A systematic form of analysis focused on text understanding and interpretation (Kuckartz, 2014) aiming to engage with the "distinctive discursive moment between encoding and decoding" (Fürsich, 2009, p. 238)	Type-building text analysis (Kuckartz, 2014) of game data resulting in 6 climate change game avatar identity types	II
		Thematic text analysis (Kuckartz, 2014) of game data resulting in 8 climate action categories (7 mitigation, 1 adaptation)	II
		Thematic qualitative analysis (Ritchie, 2013) of player data resulting in a thematic framework of gameplay experience	III
Quantitative data analysis	Analysis of aggregate data through methods such as descriptive statistics (when it applies to the data collected) and significance testing (Lazar et al., 2017). Here, part of the experimental research section.	Descriptive statistics include, e.g., means, medians, standard deviations, percentages, and visualizations such as box plots; statistical tests include both parametric and non-parametric ones	IV, V
Game design and development	The process of ideating and making a game	A process of context exploration, design space development, refinement and making, and assessment and learning (Gaver, 2014) to create a multi-platform digital game based on and for use in research *Climate Connected: Outbreak*	III, IV, V
Qualitative user study	Known as user research, representative users are invited to complete representative tasks using a system to learn about the system, the users, and their interaction (Lazar et al., 2017)	Gameplay observation and interview of 12 participants about their game experience and climate change engagement aspects	III
Experimental research	Empirical research in which participants are randomly allocated to different treatment groups (Aveyard, 2014) and suitable for establishing causal relationships (Petticrew & Roberts, 2008)	Lab-based experiment with 105 participants, three treatment groups (immersive VR game, PC game, text-based control), and multiple outcomes assessed based on self-reported data (enjoyment, immersion, learning, climate change attitudes, environmental self-efficacy, PEI, PEB)	IV, V

3.2 Systematic literature review

A systematic literature review (SLR) was conducted in Publication I, while an SLR-inspired method of game search and screening was followed for Publication II. SLRs “adhere closely to a set of scientific methods that explicitly aim to limit systematic error (bias), mainly by attempting to identify, appraise and synthesize all relevant studies (of whatever design) in order to answer a particular question (or set of questions)” (Petticrew & Roberts, 2008, p. 9). The goal was to summarize the extant empirical research on gamified climate change engagement, which would suggest future research directions (Paré et al., 2015). In accordance with the critical realist approach, we did not limit our sample to certain methods, although we scrutinized further, for precise evidence, designs less susceptible of bias (e.g., controlled studies) and those allowing to attribute effects reliably (such as before-after studies).

3.2.1 The systematic literature review process (Publication I)

The process in Publication I followed a protocol detailing how four stages would be cleared: planning, selection, extraction, and execution (Okoli, 2015). The planning identified the study's purpose—to recognize the populations and contexts (RQ1.1), designs (RQ1.2), outcomes (RQ1.3), and quality and strength of the results (RQ1.4) associated with gamified interventions for climate change engagement. With this goal in mind, a research protocol detailing the steps to follow was drafted.

The selection stage consists of literature search and practical screening to select and discard studies (Okoli, 2015). The search was performed as a combination of automated database search (Scopus, Web of Science, EBSCOhost GreenFILE, ProQuest Central, IEEE Xplore, and Google Scholar) conducted in February of 2020 and a forward snowball sampling of the studies selected through the database search. After gathering insight from previous research and some pilot searches, the search string used was:

> ('climate change' OR 'global warming' OR pro-environmental OR (environment* OR ecolog* AND sustainab*) OR greenhouse OR low-carbon OR 'energy efficien*' OR 'energy consum*' OR 'circular economy' OR 'recycl*' OR 'extreme weather' OR 'extreme event' OR 'environmental acti*') AND (gamif* OR 'game-based' OR 'board game' OR 'card game' OR 'video game' OR videogame OR 'digital game' OR 'mobile game' OR 'online game' OR 'computer game' OR 'serious game' OR 'educational game' OR 'role-playing game') AND NOT 'game theor*' AND NOT computing.

The study selection was based on two sets of inclusion criteria. The first one, content applicability, includes (a) describing a gamified climate change engagement intervention, including the provision of knowledge or engagement with climate change mitigation or adaptation practices, (b) explicitly connecting mitigation or adaptation to anthropogenic climate change, thus excluding interventions that anchor the need for pro-environmental attitude and behavior on other reasons, and (c) reporting empirical results. The second set of inclusion criteria requires the included studies to be in English and peer reviewed. The process from the first 1476 results to the final selection, which was conducted by myself and one of the co-authors of Publication I, can be seen in Table 2. We screened the studies in two phases: first, we read titles and abstracts to discard obviously unrelated articles, and then read the remaining ones in full and decided to retain or discard them based on the inclusion criteria. Decisions were made independently and then discussed until consensus was reached. In the end, 64 publications remained.

Table 2. The database and snowballing search processes. This table is part of the supplemental files of Publication I.

Criteria	Studies removed	Studies retained
Database search process and results		
All results		1476
Unique results (removal of duplicates)	-489	987
In English	-20	967
Content criteria fulfillment	-840	127
Target publication type	-19	108
Accessible	-13	95
Empirical and results reported systematically	-43	52
Not published in a more advanced version elsewhere	-1	51
Snowballing process and results		
All citations		547
Unique results (removal of duplicates within forward snowballing searches)	-110	437
In English	-22	415
Unique results (removal of duplicates with initial database result)	-44	371

Criteria	Studies removed	Studies retained
Content criteria fulfillment	-351	20
Target publication type		20
Accessible		20
Empirical and results reported systematically	-6	14
Not published in a more advanced version elsewhere	-1	13

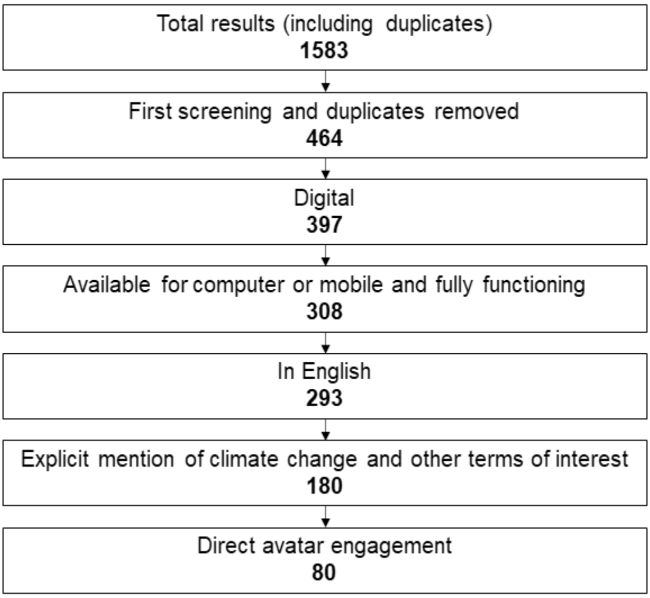
The data extraction stage identified relevant features in the publications selected based on the research questions. The two same researchers conducted this process, first extracting data independently and later aggregating and discussing the findings until a consensual result was reached. The findings were classified into five groups: bibliographic information; population and context (RQ1.1); intervention content and design (RQ1.2); engagement results (RQ1.3); and quality and strength (RQ1.4). The final step, execution, led to the writing of Publication I.

3.2.2 The digital game search and screening process (Publication II)

Before engaging in quantitative content analysis in Publication II, a game search and screening inspired by the literature review process was followed. In this case, the search for digital games including forms of climate action used three sources: a personally curated collection initiated with previous research (Fernández Galeote & Hamari, 2021); a Google search conducted in August 2020 using the string *(game OR gamification) AND ("climate change" OR "global warming" OR "climate impact" OR greenhouse OR CO2 OR emissions OR footprint OR mitigation OR adaptation)*; and searches in 21 game databases and platforms.

The screening process (Figure 2) followed two steps: first, games whose title and descriptive materials were disconnected from climate change or climate action were excluded; second, the remaining games were subjected to inclusion criteria, including the game being available for Windows PC, Mac, Linux, Android, or iOS, in English, explicitly mentioning climate change, global warming, and/or greenhouse gas emissions, and engaging the player-avatar directly in climate change mitigation or adaptation.

Figure 2. Digital game screening process as it appears in Publication II (work licensed under a Creative Commons Attribution International 4.0 License).



3.3 Qualitative content analysis

In this dissertation, qualitative text analysis was applied in two publications, II and III. Publication II takes as the object of analysis climate change action digital games and their paratexts, including manuals, videos, and player-generated online content, used to deepen game understanding. Publication III collects data from a user study through notetaking from observation and interviews and presents an analysis of player experiences and later processes of meaning-making. However, the player experience analysis done as part of Publication III was different from the qualitative content analysis used for the game analysis and will be explained in Section 3.5.5.

Qualitative approaches to data analysis are varied and no unified theoretical and methodological bases exist for all of them (Flick, 2007a, as cited in Kuckartz, 2014). Thus, the qualitative text analyses in Publications II and III should not be taken as representative of all forms of doing qualitative content research. For example, classical content analysis focuses on collecting and analyzing content as can be directly read in a text, while qualitative text analysis gives importance to text understanding and interpretation (Kuckartz, 2014). However, the process remains systematic and follows quality standards (Kuckartz, 2014), and when applied to an artifact, its goal remains to engage with the "distinctive discursive moment between encoding and decoding" (Fürsich, 2009, p. 238) to examine its structure, symbolism, and potential for persuasion (Fürsich, 2009).

Despite its diversity, qualitative analysis should aim to use measures to strengthen the method's validity and reliability. In Publication II, especially because I was the only researcher involved in coding the data, the categories created were precisely defined and extensively described, examples were used for explanation, exceptions reported, my own background described, and games were played for as long as their perceived complexity suggested would be necessary—two hours on average—to experience their relevant systems and narratives, including reading manuals, menus and encyclopedias for data acquisition and triangulation, and the notes taken were updated and harmonized throughout the collection process (Creswell, 2013; Kuckartz, 2014; Lankoski & Björk, 2015). Although Publication III involved two researchers in the data collection process, and three throughout the data analysis process, extra steps were taken to support reliability and validity. To support reliability, the data collection and analysis processes were communicated transparently and with detail. To support measurement validity, two data sources were used, observation and interview; for internal validity, systematic data collection and analysis processes were followed; for external validity, we used a diverse sample in terms of digital games use and environmental knowledge.

3.3.1 Type-building text analysis (Publication II)

Publication II followed a type-building text analysis process (Kuckartz, 2014) to classify avatar identities (RQ2.1). This form of analysis clusters elements, e.g., games, by similarity in relevant attributes, which results in different types composed of similar cases (Kuckartz, 2014). In Publication II, the attributes of interest were norms and the avatar's ultimate goal as defining aspects of the avatar. Because both are equally important, similarities needed to exist in both at the same time for cases to belong to the same type. The process followed included the following steps:

1. Determine the purpose for type-building. In this case, to identify avatars' potential for climate change engagement through (a) similarity between the avatar's and the player's identity, (b) capacity to inspire new action, and (c) representation of other agents' motives and perspectives.
2. Define the attribute space and the data of interest. This includes norms and ultimate goals as the attribute space and both linguistic messages and gameplay design as data.

3. Thematic coding of the data, in this case, both quotations from the games and other materials and my own descriptions of gameplay.

4. Choice of a specific type-building method. In accordance with the inductive method followed, given the lack of precedent in terms of climate change identity classifications and the inadequacy of using real-world classifications to map game identities directly, polythetic type-building was selected. This method departs from the empirical data to group cases by similarity.

5. All cases, i.e., games, are assigned to a type. Types were presented and described.

3.3.2 Thematic text analysis (Publication II)

To study the climate actions afforded by the games (RQ2.2), Publication II followed a different qualitative text analysis method, thematic text analysis. Of the various types of qualitative text analysis, each with their own analysis strategies, thematic qualitative text analysis is perhaps the most used (Kuckartz, 2014). Thematic analysis "involves discovering, interpreting and reporting patterns and clusters of meaning within the data" (Ritchie et al., 2013, p. 345) through a systematic process of reading, identifying topics, and integrating them into larger themes appropriate for answering the research question (Ritchie et al., 2013). Much like qualitative research overall, thematic analysis can be underpinned by multiple theories, used in many disciplines, articulated in multiple ways (Ritchie et al., 2013), and applied to cultural artifacts beyond written texts (Kuckartz, 2014).

The process followed includes the coding of data along two categories, mitigation and adaptation. Mitigation actions were grouped into subcategories based on existing mitigation models and literature (Cohen-Shacham et al., 2016; Paris Reinforce, n.d.; UK Department of Energy and Climate Change et al., n.d.; Wibeck, 2014) and inductive category building for those that did not fit existing models. Finally, the categories were contrasted and re-examined.

Other categories examined in Publication II required simple processes. Some were derived from the actions identified—climate issues (RQ2.3) are determined by the nature of action, whether mitigation or adaptation, and the spatial context depends on the scale of action and whether it is real-world action. Others were binary, such as the need for climate action to complete the ultimate goal (RQ2.4).

3.4 Game design and development

For the empirical studies described in Publications III-V, a new game was developed, *Climate Connected: Outbreak*, using the Unity engine (version 2020.3.19f1). The game has been published as a supplemental material to a design article and is therefore freely accessible online (Fernández Galeote et al., 2023a). A gameplay summary video can be found in the supplemental files to Publication V. A longer gameplay video is also available online (ACM SIGCHI, 2023). Considering game design as a method relevant to this dissertation, this subsection describes the design process, the game's content, its gameplay, and further principles applied.

3.4.1 Design process

The game's design followed a process of context exploration, design space development, refinement and making, and assessment and learning (Gaver, 2014). The context identification and exploration phase took place between 2020 and the Summer of 2021. As explained, I first focused on identifying gaps and design directions through Publications I and II. During the first half of 2021, I collected the first literature on content and best practices in areas such as design, learning, communication, and experimental research. The design space development phase occurred partially in parallel with the previous phase. During this process, dozens of ideas were written and considered until I committed to a single concept in June of 2021—a flowchart with the climate and health issues that would feature in the game.

Refinement and making started the next month, in which the basic genre and gameplay mechanics were defined as those of linear narrative games to provide an artifact that was both easy to use and comparable to a control condition. Then, a text-based prototype was developed using the Twine (version 2.3.14) software. The prototype, which described the exploration of the game space to find objects that would then lead to completing a flowchart, was shared with supervisors and colleagues for feedback. During the Summer of 2021, various discussions and testing sessions took place. Then, I started the development after agreeing on the different versions that the game would feature—for the purpose of this dissertation, desktop PC and immersive VR, but also two different sets of content based on the in-game location that may lead to future studies. Between September 2021 and February 2022, I developed the immersive VR version of the game. Confidants and experts were invited to test various alpha and beta versions, which led to substantial improvements such as simplifying the content and adding minigames. In March 2022, the PC version was developed.

The final phase, assessment and learning, consisted of an investigation of how people reacted to the design. Testing sessions were arranged until June 2022, but more importantly two research events integrated this phase—the user study described in Publication III, and the experiment described in Publications IV and V. For Publication III, whose data collection took place in April 2022, an advanced beta of the PC version was used. For the experiment, conducted between August and November 2022, a final version for PC and Quest 2 VR headsets was used. This version included various changes—minigames that were not understood were significantly improved; in other minigames where issues were also found, more guidance about their meaning and goals was provided; more clues were added, both textual and visual; unclear visual elements were changed and sound was improved, including the addition of music; the amount of text and its level of sophistication were reduced; and the actions done in the game were linked more explicitly to their real-world counterparts.

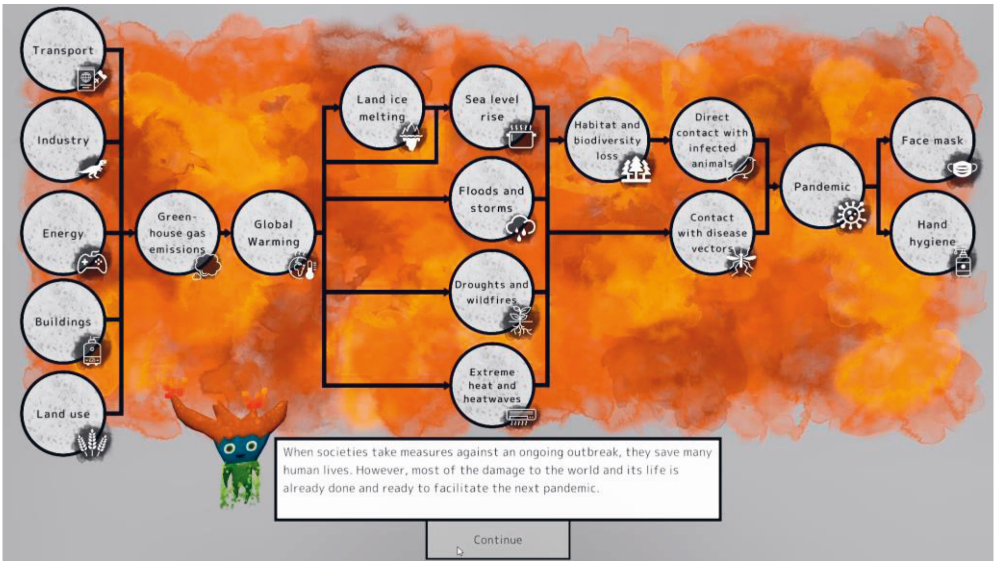
In technical terms, the game was built as a single Unity project despite being multi-platform. Every scene in the project contained the elements required for both versions, and building the executable software for either of them could be done by changing a single variable in the project. The use of JSON files for the in-game text allowed the coexistence of more than one version with parallel content which could be also switched changing a single parameter. For data collection, the game saves participant choices as local files throughout the session.

3.4.2 Content

Climate Connected: Outbreak links the causes, manifestations, impacts, and solutions of climate change, with a particular focus on zoonotic infectious diseases and wellbeing, both human and non-human. In doing so, it aims to evince the links between environmental, animal, and human health, and the ways in which climate change endangers all of them (UNEP, 2021). Through a linear story in which players find items and overcome challenges, the game connects large planetary issues with local impacts and day to day issues and proposes climate change mitigation to address interconnected problems at the root, i.e., climate change (see Figure 3).

The information about climate change and infectious diseases is taken from multiple scientific and educational resources (including, e.g., IPCC, 2021; Knowlton et al., 2021; Pinkerton & Rom, 2021). The game's content was shared at various stages with three experts who offered insights in atmospheric and climate science, global change, sustainability, environmental policy, and science communication.

Figure 3. The complete in-game flowchart depicting all the issues included in the game. From left to right, five sectors that can emit greenhouse gases, leading to global warming; physical manifestations of climate change; impacts of climate change on human and non-human well-being; and two example measures against the spread of pandemics.



3.4.3 Gameplay

The game consists of four chapters (see Figure 4). The first one takes the player to the year 2050, where a positive and sustainable vision of the future is soon replaced by a world ravaged by a pandemic in which ecological crises such as climate change continue to worsen. The player meets a nature spirit, Saga, who proposes to discover together the connections between the disease and climate change. For this, the player must find a series of quotidian objects around the game's hub space, which represents their future apartment.

The second chapter is based on a game loop that repeats for each of the 14 objects in the game: the spirit presents a riddle that refers to an object in the house, which in turn is paradigmatic of a systemic phenomenon. When the object is found, the player completes a small minigame associated with it (see Table 3 for a description of each minigame and Figure 5 for some visual examples). Then, a new concept is introduced as part of a growing flowchart showing the connections between causes and consequences of climate change.

The third chapter is a quiz about the chart's nodes. In the fourth chapter, Saga asks the player about their feelings on climate change (e.g., alarmed, concerned, unsure, skeptic) and proposes engaging in climate action as a method for bringing a sustainable future. If the player agrees, they can choose between six climate action types, including both individual and collective forms.

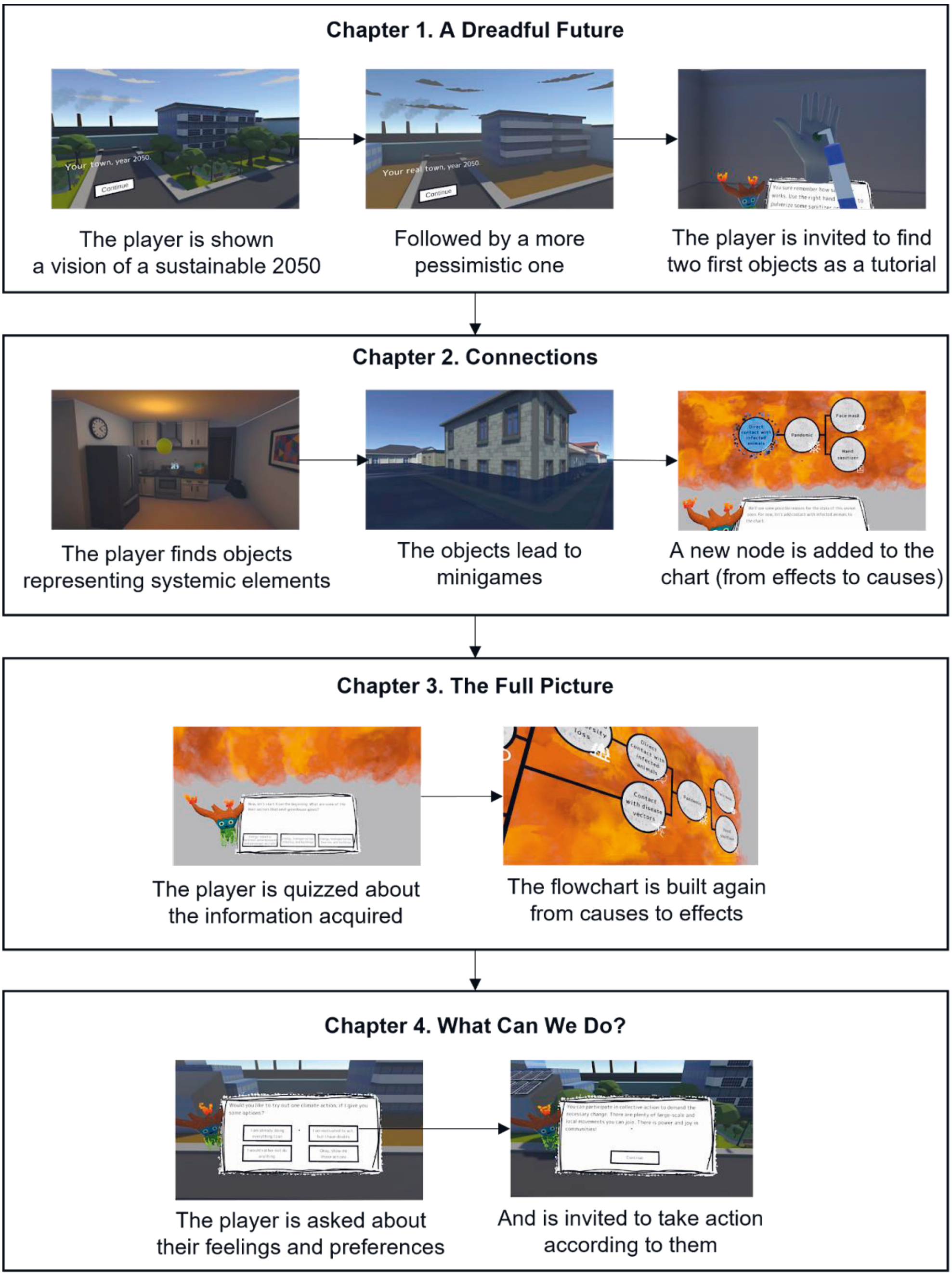
Table 3. The minigames as they appear in the game. Nodes associated to minigames are grouped here in categories. In the minigames, the players interact with elements while reading explanations about the issue represented. Adapted from a table in Publication V (work licensed under a Creative Commons Attribution International 4.0 License).

Category	Node	Minigame
Pandemic consequences	Hand hygiene	The player is given a hand sanitizer bottle, which they must spray and spread on their hands. This minigame is part of the tutorial-like introductory chapter.
	Face mask	The player is given a box of masks and they must throw them o approaching figures to prevent contagion. This minigame is part of the introductory chapter.
Climate change impacts on life	Direct contact with infected animals	The player embodies a bird pursued by a red cloud representing environmental degradation. Every time the player moves, the cloud extends. As the cloud spreads, the only option left is to migrate to the city.
	Contact with disease vectors	The player must place a mosquito net over a door before the time limit, applying glue first and then affixing the net to the frame. If they fail, the mosquitoes arrive with the nighttime and they must repeat the process.
	Habitat and biodiversity loss	The player is shown a forested area crossed by a river and encouraged to build on it. As they select each segment, the forest gets cleared for construction and a river mammal's death is revealed as a consequence.
Physical manifestations of climate change	Droughts and wildfires	The player is surrounded by trees on fire which they can extinguish using a water hose that they have equipped, but no matter how fast they stop the fire, the trees cannot be saved.
	Extreme heat and heatwaves	The player is in the street during a scorching heatwave, represented by an orange hue covering everything and dead birds at different spots. The player must find the only safe place, a garage with air conditioning.
	Floods and storms	The player is in the middle of a flooded area. Since the stagnant water, reeds and accumulated leaves have allowed mosquitoes to breed in various places, they must find and remove such places.

Category	Node	Minigame
	Land ice melting & Sea level rise	At the seafront of a town, facing the ocean and some distant ice formations, the player witnesses how sea level has risen in the past century and is forecasted to rise in the coming century, including the possibility of rise that submerges part of the surrounding town and surfaces multiple dead fishes around them due to warming.
Causes of climate change	Buildings	The player turns on water heating to prepare a hot bath, but this makes a fossil-based power plant appear behind as the infrastructure heating the water. They also turn on the air conditioning, which is revealed to emit potent greenhouse gases. The player turns them off before ending the minigame.
	Land use	The player is in a farm. With a hose, they water some cereal crops, but when they have grown they are eaten by a cow, signifying the extensive use of cereals to feed animals. Then, as climate change progresses, the yield becomes smaller, but the animal keeps eating. In the end, the player closes the barn doors to reduce cattle farming and therefore promote food security.
	Industry	The player is tasked with packing plastic toys. After this, a more pro-environmental option is presented, a toy made of wood, combined with the reduction in consumption.
	Energy	First, the player plays a shooting game in which each shot increases their "CO2 score", pointing towards the relationship between electronics and energy use. After this, they must disconnect the power going from a fossil fuel power plant and switch the energy source to wind turbines instead.
	Transport	The player sees the number of airplane tickets and soft drinks bought per second. Then, they can throw a hammer at the screen to represent a break with consumerism associated with, e.g., certain types of tourism.

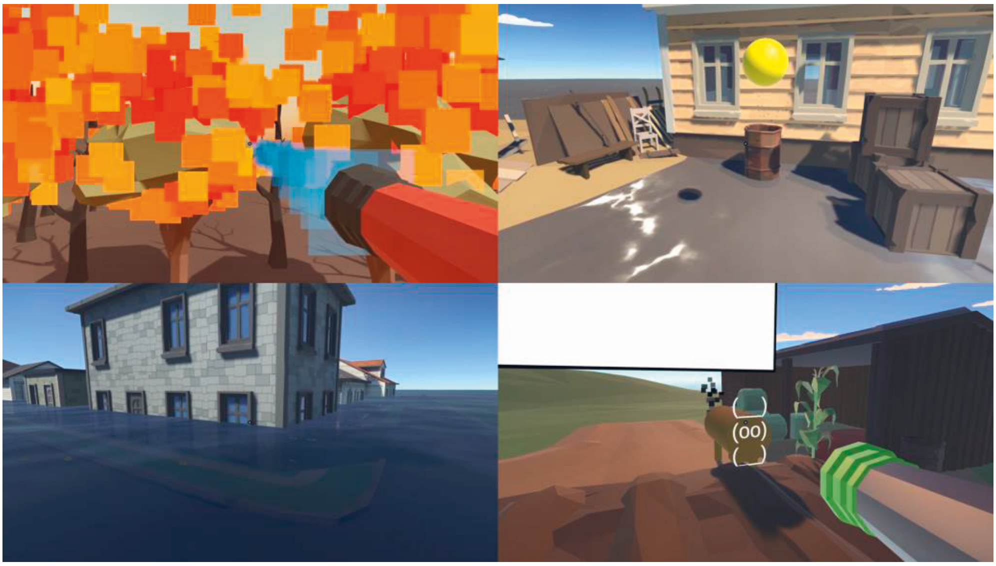
After the experiment, participants received an email with more specific action-oriented information based on their choice. By suggesting real-world action and supporting it with the email, the game aims to bridge the conceptual divide between serious games and gamification as traditionally understood (Deterding et al., 2011; Landers, 2014; Plass et al., 2015). In other words, the intervention combines top-down education, as is typical of serious games, with a bottom-up gamified approach that allows players to choose based on their feelings, thoughts, and context.

Figure 4. The game's structure as it appears in Publication III (work licensed under a Creative Commons Attribution International 4.0 License).



The gameplay is based on simple mechanics in both the PC and the immersive VR versions. Players enact three basic types of action using a single button, either the PC's mouse or a trigger in the VR controller—selecting options in dialogs, teleporting through 3D spaces, and interacting with items. VR players can grab and throw objects in a more elaborate way using hand tracking, but both versions are designed to feel simple to use, natural, and to minimize motion sickness thanks to the teleportation mechanic.

Figure 5. Some issues included in *Climate Connected: Outbreak* as minigames—droughts and wildfires, represented via a forest fire that must be put out; floods and storms, after which the player must find mosquito breeding grounds; land ice melting and projected sea level rise, which occurs in front of the player for the whole 21st century; and land use change, represented by a cow that keeps eating the player's crops.



3.4.4 Principles informing game design choices

Multiple aspects of the game's content and gameplay explained above can be linked to principles and perspectives found in multiple areas of practice and scholarship. The game considers the three dimensions of climate change engagement: cognitive, affective, and behavioral (Lorenzoni et al., 2007). At the cognitive level, the content presented in the game follows pedagogical guidelines by aiming to support declarative knowledge, by raising awareness of climate change and its systems throughout the adventure; procedural knowledge, by explaining to players some of the actions that they can take in their real life; and effectiveness knowledge, by characterizing single behaviors as just a step in a long journey towards a sustainable life and explicitly categorizing consumer behaviors based on their impact, if the player chooses that path at the end of the game (Kaiser & Fuhrer, 2003).

Thus, the way in which the information is presented has clear behavioral implications. The game aims to extend the player's role beyond consumption to encourage other forms of citizenship (Stern, 2000; Wibeck, 2014) and encourages real-world action with categories informed by various sources (e.g., Stern, 2000; Wibeck, 2014; Wynes & Nicholas, 2017). Behavior is supported through principles found in the motivation literature. First, considering the player's profile in relation to climate change (Roser-Renouf et al., 2015). Second, encouraging autonomous decision-making to foster intrinsic motivation (Cooke et al., 2016) by presenting various action paths to choose from. Third, supporting the player's strategy, capacity, and effort beliefs (Pelletier et al., 1999) by allowing them to express doubts and ambivalence. Fourth, framing climate action as a meaningful way to sustain personal, collective, and planetary well-being in the face of the climate crisis (Ojala, 2012).

The game also follows climate change communication research recommendations (Sheppard, 2012) to align the issue with all three dimensions of engagement. As explained in Section 3.4.2, information is presented throughout the game in a way that is visual, local, and connected to the player's day-to-day reality. Visual, because reality is not only presented through text, but salient issues are also distilled into interactive 3D environments (see the minigame descriptions in Table 3). Local, because it shows the proximal impacts of climate change, rather than focusing only on, e.g., large scale readings and forecasts; in addition, the game ends with a call to action in the player's real environment. And connected, because the fictional story leads players from quotidian elements (e.g., a plane ticket) symbolically connected with larger individual topics (long-distance air transportation and consumerism) to systemic issues related to climate change (the greenhouse emissions derived from such activities, and the consequent effects on the climate and the well-being of life on Earth). In addition, framing climate change as a health and well-being issue in the game, which is topical, relatively unknown (van Wijk et al., 2020), and potentially productive (Badullovich et al., 2020; Walker et al., 2018) is a gap and opportunity identified in previous literature (Fernández Galeote & Hamari, 2021) and in Publications I and II.

Storytelling principles are used to reinforce learning (Plass et al., 2015) and emotional impact (Hemenover & Bowman, 2018). The fundamental elements of the story are the guiding character; the clear goals that this character gives to the player throughout the story and as an overarching aim, which guide the player's action and progress; and the player's own identity—their future self, who lives at a time in which consequences from present inaction have worsened. Learning is supported by following a logical narrative from consequences to causes, while emotional impact is reinforced through (a) visual and interactive situations where meaningful problems and solutions are depicted and enacted, and (b) the unraveling of a system connecting seemingly small actions and events that the player is likely to have experienced multiple times with large-scale issues.

From game-based learning and gamification, the game is broadly designed to be an educational artifact (Plass et al., 2015) by allowing players to learn experientially in an interactive world (Monroe et al., 2019) and to develop embodied and grounded cognition (Barsalou, 2008; Li et al., 2020) through their actions in the minigames. Various game-based learning principles (Gee, 2007) were considered for the design, including the explicit player identity as their future self; a story that develops through the gameplay; world interactions involving input and feedback; explicit links between concepts and experiences to create situated meanings; resignification of day-to-day elements to promote lateral thinking; a content and progression that support systems thinking; a balanced challenge fine-tuned through playtesting; the provision of information strategically; and a quiz-based evaluation to consolidate knowledge. Beyond the virtual world, the game is also considered as a springboard towards behavioral change (Hamari, 2019).

In addition, various capabilities of multimedia technology were explicitly utilized, allowing the game to feature interactive visualizations for climate change engagement (Moser, 2010; Wibeck et al., 2013) and inviting behavior that may lead to self-efficacy (Lehikko, 2021; Petersen et al., 2020). Specific multimedia learning principles (Mayer, 2009) were applied, including combining text and visuals in proximity and simultaneously; using simple language; showing the game structure to the player; dividing the content into concepts; and using non-intrusive background music, which was a player expectation in playtests but should not distract from the core information and interaction. Finally, the affordances of immersive VR, such as head and controller tracking, were consciously used in various minigames for attitudinal effect and psychological distance reduction (Breves & Schramm, 2021; Markowitz & Bailenson, 2021), for example when embodying an endangered bird, putting out a forest fire, witnessing sea level rise, and breaking a screen.

3.5 Qualitative user study (Publication III)

Publication III follows principles of usability testing in human-computer interaction, or user research, where representative users are invited to complete representative tasks using a system, which can lead to learn more about the interface being examined but also about people and their forms of interaction with it (Lazar et al., 2017). Typically, usability testing aims to find and fix flaws in a system and to evaluate solutions, rather than understand problems and phenomena (Lazar et al., 2017). However, in this case, beyond improving a beta version of the game, the goal was to understand the player experience in broad terms, including not only how they interacted with the system but also various climate change engagement-related outcomes. Thus, the study extended this form of user research, but it maintained other principles—usability testing typically uses a small number of participants, involves observation without researcher participation, is a short-term method, and contributes to systems and interface development (Lazar et al., 2017).

3.5.1 User study design

The exploratory study described in Publication III was conducted to understand the way in which participants interacted with and experienced a serious game about climate change that I designed and developed for the needs of this dissertation—*Climate Connected: Outbreak*. The focus of interest included how they followed the designed path (RQ3.1), failed to do so (RQ3.2), deviated from it (RQ3.3), and how the game engaged them, or not, with climate change (RQ3.4). Twelve participants were recruited, and data was collected as written notes from full gameplay session observations and short post-game interviews.

3.5.2 Participants

The 12 participants (6 female, 5 male, 1 declined to answer) played the game individually on a computer located in a dedicated space. The recruitment call was an open request for volunteer participants sent to the local network of the researchers conducting the intervention. Thus, the participants emerged mostly from their academic environment. The participants self-reported different degrees of experience with video games and knowledge of environmental topics, so they were divided into four groups of three depending on their gaming experience (high/low) and environmental knowledge (high/low). Eleven participants (one declined to answer) reported their ages, which ranged from 20 to 35. The median age was 24.

3.5.3 Materials

Apart from the note-taking materials, this study used the game *Climate Connected: Outbreak*, described above. Although two versions of the game have been developed, one for immersive VR systems and one for regular computer screens, Publication III used the computer screen version, in particular an advanced beta version.

3.5.4 Procedure

Data collection took place in April of 2022 at the University of Oulu by three of my co-authors. In advance, individual participants declared their degree of game experience and environmental knowledge. Then they arranged a time for the on-site intervention. There, they provided their informed consent based on an information sheet and data privacy statement, created a climate change concept map, played the game from start to end, and revised their concept map. During the sessions, two researchers noted down player actions and comments. Players completed the game in 47 minutes on average (min. 32, max. 64). The participants were able to choose one form of climate action but did not receive the corresponding email after the session, unlike participants of the experimental studies.

After completing the game, participants were interviewed about the game's usability (issues encountered, discomfort experiences), playability (likes and dislikes, including suggestions for improvement), and engagement with the game and climate change. Questions about engagement included cognitive (learning), emotional (feelings), and behavioral aspects (reflections on their life and actions).

3.5.5 Data analysis

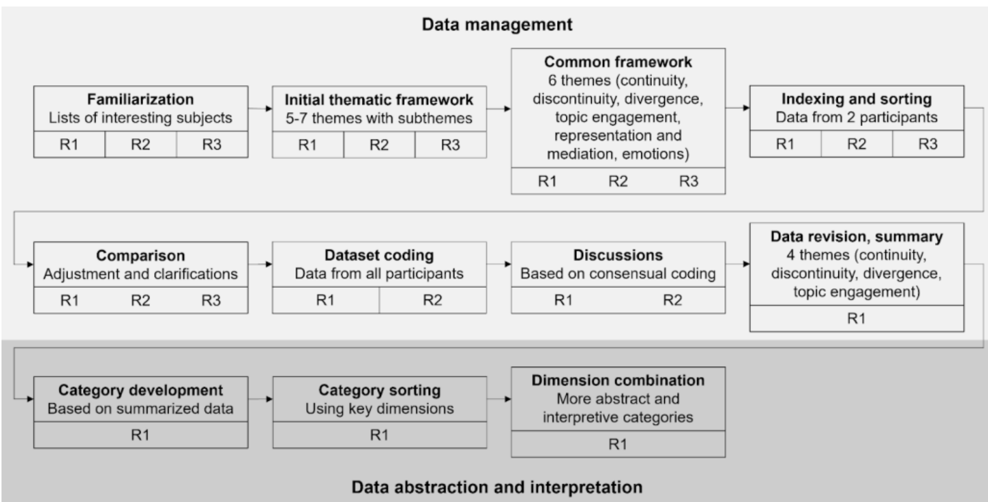
The thematic analysis followed in this study, summarized in Figure 6, included two stages—data management and data abstraction and interpretation (Ritchie et al., 2013). Data management started with familiarization, where I and two co-authors read the data and listed interesting subjects in relation to the research question, individually. After this, we built an initial thematic framework organizing the data in

5-7 themes and however many subthemes, also individually. Then, we met to create a common framework to tag the data using its themes and subthemes as codes. This first framework contained six themes: (1) continuity, or progressing as the design intended; (2) discontinuity, or unforeseen interruptions; (3) divergence, or departures from the designed path without blocking progress; (4) topic engagement, in this case climate change; (5) representation and mediation, or moments when players engage with core game elements; and (6) emotions, including described and observed.

After these steps were completed, we indexed and sorted the data using ATLAS.ti (version 23), where we first tagged two participants' data and met to compare our results. After adjusting and clarifying some subthemes, I and another researcher coded all the data independently. Following consensual coding (Hopf & Schmidt, 1993, as cited in Kuckartz, 2014), we discussed until we reached a satisfactory outcome. Then, I used ATLAS.ti to re-read the labeled data, created a matrix for each theme including the subthemes and the participants, refined the data, and turned the last two themes of the initial thematic framework into subthemes.

Next, I engaged in abstraction and interpretation using spreadsheets and text documents, developing categories from the summarized data to capture the different ways in which themes and subthemes occur. Categories were then sorted by key dimensions of player experience and behavior. These dimensions were combined to form more abstract and interpretive categories capable of addressing the research questions through a more meaningful understanding of phenomena and their related data (Ritchie et al., 2013).

Figure 6. The data analysis process followed for Publication III. R means researcher. Vertical separating lines indicate that a step was done individually.



3.6 Experimental research (Publications IV and V)

Certain empirical research designs are particularly suited to different types of inquiry. Questions about effectiveness, i.e., does a particular treatment cause a desired effect, and does it have a larger effect than another treatment, benefit from the use of designs that are suitable for establishing causal relationships, such as randomized controlled trials (CRTs) (Petticrew & Roberts, 2008). Accordingly, experimental methods in which participants are randomly allocated to different treatment groups, including a control condition which may consist of no treatment or a standard treatment, are considered reliable in detecting cause-effect relationships (Aveyard, 2014). Thus, to explore the potential of *Climate Connected: Outbreak* in comparison with traditional media, an experimental study with random allocation and three conditions was designed—immersive VR game (hereafter, VR), computer screen game (PC), and text with charts (control). This study led to Publications IV and V, where Publication IV focuses on learning (RQ4) and Publication V focuses on other engagement indicators (RQ5). The quantitative data used in these publications will be made accessible through the Finnish Social Science Data Archive (Fernández Galeote et al., 2023b). The study complied with TENK's ethical guidelines and national and European data protection regulations, and was approved by the university's DPO.

3.6.1 Experimental design

The experiment took place at Tampere University. Its goal was advertised as understanding participants' experience with different forms of immersion in climate change information, including the effects of various communication methods. Digital and physical elements were used for promotion at the university and city-wide. The promotional materials contained the warning that VR may be used, so wearing glasses should be avoided if possible. Any adults who provided their informed consent were eligible. As compensation, participants received a movie ticket. Participants were randomly allocated to one of three groups: VR, PC, and control. We recruited the largest possible sample that our financial, time and human resources allowed. Towards the end of data collection, the last participants' gender was minded when allocating them to different groups so that the distribution across groups was similar. This was done because gender is a potentially relevant variable in climate change engagement (Gifford & Nilsson, 2014) and, unlike others, it was operationalized as a variable with three values, which permitted simple balancing.

3.6.2 Participants

The study uses the data from 105 participants, with 35 having been allocated to each of the three conditions. The average age (control=29.29; PC=28.57; VR=30.63, see Table 4) and gender distribution (control: Female=20, Male=14, Other=1; PC: F=20, M=14, O=1; VR: F=21, M=13, O=1) were similar in all three. The self-reported educational level of the participants typically involved some form of university education—university of applied sciences bachelor's degree (n=14), university of applied sciences master's degree (n=2), university bachelor's degree (n=27), and university master's degree (n=48). The rest had attained primary education (n=1), vocational school or course (n=2), general upper secondary education (matriculation examination) (n=10), or vocational college (post-secondary) (n=1) education. The three conditions had similar numbers of participants with university education (control: 31; PC: 29; VR: 31). Participants were from Finland (n=35), Asia (n=24), other EU countries (n=23), the US or Canada (n=5), non-EU Europe (n=4), Africa (n=3), Middle East (n=3), and Latin America (n=2). Six participants came from elsewhere in the world.

Table 4. Participants' distribution per age group. This table appears in Publication IV (work licensed under a Creative Commons Attribution International 4.0 License).

Age group	n	$n_{control}$	n_{PC}	n_{VR}
18-20	8	1	6	1
21-25	33	12	9	12
26-30	26	8	10	8
31-35	16	7	4	5
36-40	14	6	3	5
41-45	2	1	0	1
46-50	4	0	2	2
>50	2	0	1	1

3.6.3 Materials

3.6.3.1 Stimuli

The final iteration of *Climate Connected: Outbreak* was used in its two versions, PC and immersive VR (see Figure 7 for a reminder of the basic gameplay loop). In addition to the game, a PDF document was created as the control. The document includes the game's informational material, the flowcharts, and descriptions of the virtual world in the game. In this way, the 4,600-word text provides all the relevant information that could be acquired by playing the game, but it does not include a specific character—although the reader is addressed in the second person—and any interactive parts—the quiz, the questions about thoughts and feelings—are described including all possible options. The final action choice is presented as a questionnaire after having read the text. The game and the text are both in English.

Figure 7. An example of the basic gameplay loop: the player finds an object (top left, in this case a dry plant), completes an associated minigame (top right, putting out a forest fire), and a new node is added to the flowchart (bottom, droughts and wildfires). This figure appears in Publication IV (licensed under a Creative Commons Attribution International 4.0 License).

3.6.3.2 Data collection

Publication IV uses a pre- and post-test 14-question questionnaire created ad-hoc to reflect the intervention's content. The questionnaire allows three answer options—true, false, or "I don't know." The question order was different before and after the treatment, but all participants answered the same questions irrespective of their allocated group. The questions address climate change causes, impacts such as drought and sea level rise, various links between climate change and infectious diseases, cereal use in the world, forms of climate action, and the possible effects of using air conditioning.

Publication V uses existing questionnaires to measure interest and enjoyment, immersion, climate change attitude, and environmental self-efficacy (for an overview of the research, see hypotheses in Section 4.5). Ad-hoc questionnaires were created to measure PEI and PEB. To measure interest and enjoyment, the Intrinsic Motivation Inventory's Interest/Enjoyment subscale (selfdeterminationtheory.org, n.d.) was used (hereafter, JOY). Its seven items were randomly ordered and rated on a 7-point Likert scale. The Cronbach's alpha value of the participant responses was 0.906, denoting excellent internal consistency. The data were computed as averages per participant. Meanwhile, immersion was measured using the GAMEFULQUEST IMMERSION subscale (Högberg et al., 2019). The Cronbach's alpha value was 0.714, suggesting acceptable internal consistency. The data were computed as averages per participant.

The Climate Change Attitude Survey (CCAS) (Christensen & Knezek, 2015) was used to measure climate change attitude. Given that previous studies have proposed only tentative factors (Christensen & Knezek, 2015; Oladipo et al., 2020), an exploratory factor analysis (EFA) was performed on the pre-intervention responses using Jamovi 2.3.21.0 (package jmv 2.3.1). Bartlett's Test of Sphericity was adequate (< .001). According to KMO measures of sampling adequacy, most items were adequate (0.8-1.0) and three were middling (0.7-0.79) (Kaiser, 1974). Using minimum residuals and oblimin rotation, parallel analysis detected a best fit with three factors.

However, model fit measures appeared not to be acceptable (RMSEA 0.094, TLI 0.850) (Hu & Bentler, 1999), so larger model configurations were explored under the assumption that smaller RMSEA and larger TLI values indicate better fit (Xia & Yang, 2019). Nonetheless, it was kept in mind that model fit indices may be too sensitive to be used in EFA (Montoya & Edwards, 2021), their cutoff values have been questioned (Xia & Yang, 2019), and best practices indicate that parallel analysis provides the largest number of plausible factors (Watkins, 2018). According to model fit measures, models with four and five factors offered better fit, but they did not seem to offer stronger theoretical explanations since the variables seemed to point towards (a) beliefs in climate change and its severity, or (b) attitudes regarding climate action. These two categories resemble the instrument's theoretical foundations, beliefs and intentions (Christensen & Knezek, 2015). For these reasons, these models were discarded.

Exploring models with three factors and fewer, the three-factor model suggested by parallel analysis was found to be problematic. One factor had only two variables, suggesting overfactoring (Gorsuch, 1983, cited in Watkins, 2018) and a third variable saliently loaded on two different factors, which also suggests that the solution is sub-optimal (Watkins, 2018). Meanwhile, a scree plot used as a subjective adjunct to the parallel analysis estimate (Watkins, 2018) indicated two factors as best fit, since the magnitude change of the component eigenvalues was markedly reduced after that. Given the issues associated with the models with three or more factors, and the existence of two theoretically justifiable constructs, the two-factor model was chosen. Factor 1 (climate change beliefs, CCBEL) includes beliefs that climate change is real, concerning, and should be known and acted upon. Factor 2 (attitudes towards individual climate action, CACT) includes attitudes towards individual action (often either "I" or "we"), which can be related to intention as an attitudinal component (Schultz et al., 2005) (see Table 5).

Table 5. EFA results on the pre-treatment CCAS scale. h2=communality. Salient pattern coefficients ≥.3 in boldface. This table appears in Publication V (work licensed under a Creative Commons Attribution International 4.0 License).

	Descriptive statistics				**Factors**		
Item	**Mean**	**SD**	**Skew**	**Kurtosis**	**CCBEL**	**CACT**	***h*²**
1. I believe our climate is changing	4.76	0.53	-2.58	7.85	**0.77**	-0.13	0.54
2. I am concerned about global climate change	4.55	0.73	-1.90	3.69	**0.76**	0.03	0.59
3. I believe there is evidence of global climate change	4.78	0.48	-2.14	3.95	**0.88**	-0.04	0.76
4. Global climate change will impact our environment in the next 10 years	4.65	0.71	-2.54	7.84	**0.73**	0.08	0.58
5. Global climate change will impact future generations	4.87	0.39	-3.10	9.59	**0.70**	-0.01	0.49

	Descriptive statistics				Factors		
Item	Mean	SD	Skew	Kurtosis	CCBEL	CACT	h^2
6. The actions of individuals can make a positive difference in global climate change	4.13	0.99	-1.06	0.39	0.19	**0.65**	0.55
7. Human activities cause global climate change	4.69	0.52	-1.41	1.07	**0.67**	0.10	0.51
8. Climate change has a negative effect on our lives	4.54	0.81	-1.97	3.98	**0.65**	0.03	0.44
9. We cannot do anything to stop global climate change (reversed)	4.29	0.91	-1.47	2.33	0.20	**0.45**	0.30
10. I can do my part to make the world a better place for future generations	4.25	0.72	-1.20	3.4	0.26	**0.36**	0.26
11. Knowing about environmental problems and issues is important to me	4.31	0.80	-1.44	2.84	**0.34**	0.23	0.23
12. I think most of the concerns about environmental problems have been exaggerated (reversed)	4.46	0.75	-1.40	1.74	**0.52**	-0.02	0.26
13. Things I do have no effect on the quality of the environment (reversed)	3.87	0.91	-0.59	0.04	0.11	**0.61**	0.43
14. It is a waste of time to work to solve environmental problems (reversed)	4.7	0.61	-2.90	12.7	**0.45**	0.13	0.27
15. There is not much I can do that will help solve environmental problems (reversed)	3.83	1.07	-0.80	-0.03	-0.12	**0.90**	0.74

The Cronbach's alpha values were satisfactory (attitudes pre=0.868, post=0.861; beliefs pre=0.869, post=0.886; action pre=0.781, post=0.729). The values for CCAS, CCBEL and CACT were computed as pre- and post-intervention averages and as pre to post change (i.e., post minus pre).

Environmental self-efficacy was measured using the 10-item version of the Environmental Self-Efficacy Scale (ESE-10) (Moeller & Stahlmann, 2019). Participants rated 10 pro-environmental behaviors on a scale of 0-10 depending on their certainty regarding whether they could do them regularly. The Cronbach's alpha values were satisfactory for pre (0.914) and post (0.880). The data were computed as averages and as a pre-post change score for every participant.

PEI was measured by asking participants if they wished to select a type of climate action of their interest, after which they would receive an email with actions that they could do. This question was presented to game players at the end of the story, while readers encountered it after finishing the text. In both cases, seeing the options and choosing one of them was optional. The six options include spreading awareness, creating with a focus on climate change, low-commitment political action, individual action, collective action, and learning more about climate change. Within the next 24 hours, participants received an email with suggestions aligned with their choice. The emails can be found as supplemental files to the game (Fernández Galeote et al., 2023a). Game players received an email written as Saga, the game's guiding character, that included a badge-like graphic according to their action choice, while readers received a text-based email from the research team. Ten days after the intervention, a final survey was sent asking them about their action, including if they had done something and if the experiment had inspired them to act beyond this one action. The email was also written differently based on the participant's treatment—game players received an email from the in-game spirit of nature that included a badge-like graphic (see Figure 8), while text readers were addressed by the researchers.

Figure 8. The badges sent to participants via email, together with information about their climate action choice.

3.6.4 Procedure

The experiment took place between August and November of 2022. Before the in-person intervention, participants answered an initial survey from home, which included demographic questions and various scales relevant to the research—e.g., about climate change attitudes and environmental self-efficacy, two attention checks, and a link to the privacy policy and information sheet. To access the survey, participants had to provide their informed consent. After completing the survey, they were able to book a time for the experiment within the following two weeks. After confirming that they had not failed any of the two attention checks in the survey, the booking was confirmed and they received instructions on how to find the lab, Ludus, at Tampere University.

Once they were at the lab, participants were greeted by one or two of the three researchers who oversaw the experiment at different times, all of whom followed the same written protocol. Next, participants were offered the possibility to read the information and privacy policy again. Then, they engaged in a cognitive mapping task. After this, they were given 10 minutes to answer the knowledge questionnaire.

Then, the treatment description started. Participants who had been assigned to the control or the PC condition stayed in the same computer where they had answered the knowledge test, located in individual soundproof cubicles with no outside view. VR participants were taken to a separate area with enough space for them to move their arms and given a Quest 2 headset with two controllers. PC players were told that they would play a game controlled exclusively with the mouse, and that they could begin whenever they were ready. VR players were told that they would play a game controlled exclusively with the controller trigger. They were asked whether they had experience with VR and the researcher used a controller to explain the game's three main interactions: selecting, grabbing, and throwing.

All participants were told that their goal was "to get as good an understanding as possible of the content of the game/text." For this, they were told that they would have between 30 and 60 minutes. Readers who finished before 30 minutes were allowed to re-read any part of the text. On average, text readers finished in 32 minutes, PC players in 40 minutes, and VR players in 43 minutes.

Immediately after completing the game or finishing the text, the participants answered the post-treatment survey, which included JOY, IMMERSION, CCAS and ESE-10; were given the opportunity to modify their concept map; answered the post-treatment knowledge test; and were offered to participate in an optional interview. Table 6 summarizes the parts of the procedure relevant to this dissertation.

Table 6. Experimental procedure and contents relevant to the publications included in this dissertation.

Test	Variables
First pre-test	- Demographics: age, gender, educational level attained, geographic origin - CCAS - ESE-10
Second pre-test	- Knowledge test
Treatment	- Text-based control/Screen-based PC game/Immersive VR game - PEI (game end/after control)
First post-test	- JOY - IMMERSION - CCAS - ESE-10 - Knowledge test
Delayed post-test (10 days)	- PEB survey: action completion status, inspiration for further action

3.6.5 Data analyses

In Publication IV, participant performance was the sum of correct answers, although sensitivity analyses involving other calculation methods were also performed, leading to no significant differences. The pre- and post-intervention questionnaire data were analyzed through a repeated measures ANOVA test to detect possible pre- to post-intervention differences in knowledge for the overall intervention (RQ4.1, within-subjects part) as well as differences in post-intervention knowledge between the three groups (RQ4.2, between-subjects part). This parametric test was selected given that the variances across groups seem to be equal and the standardized residuals of the model are approximately normally distributed, according to a Levene's test and Q-Q plot examination.

However, and for additional robustness given non-normality in some of the individual factor levels involved in the analysis, the repeated measures ANOVA was complemented with non-parametric alternatives. For the within-subjects part (RQ4.1), Wilcoxon rank tests were conducted for the overall sample and each of the three groups, while the between-subjects part (RQ4.2) was complemented with a non-parametric analysis of covariance (ANCOVA) using the fANCOVA package (version 0.6-1) (Wang & Ji, 2020) in R (version 4.2.2), controlling for the participants' initial knowledge. To answer RQ4.3, descriptive data of the participants' answers were tabulated and the patterns detected for each question were compared with the way in which the content is presented in the game.

In publication V, differences between pre- and post-treatment averages were tested using Wilcoxon signed-rank tests when the data did not seem to be normally distributed based on Shapiro-Wilk tests, skewness and kurtosis values, and/or Q-Q plot observation. The tests conducted were one-tailed where a hypothesis justifying the choice existed. When testing a hypothesis involved multiple tests on the same population and the results appeared to be significant, a Holm-Bonferroni correction was applied—this was the case with results involving CCAS and one of its dimensions, CCBEL or CACT, for the same treatment group.

To test if significant differences existed between the three groups, whether in average scores (JOY, IMMERSION) or in shifts between pre- and post-treatment (CCAS, CCBEL, CACT, ESE-10), one-way ANOVA tests were conducted when tests of normality (Shapiro-Wilk) and homogeneity of variance (Levene) indicated that the data fulfilled the assumptions for parametric testing. Where this was not the case, the non-parametric Kruskal-Wallis test was used. When these tests were significant, Dwass-Steel-Crichtlow-Fligner pairwise comparisons were performed and Cliff's Delta Calculator (Instituto de Investigación de la Facultad de Psicología y Psicopedagogía de la Universidad del Salvador [IIPUS], n.d.) was used for effect sizes. To test for correlations between IMMERSION and CCAS/CCBEL/CACT/ESE-10, Spearman's rank correlation coefficient was used to detect possible monotonic relationships. Finally, $\chi 2$ tests of independence and Fisher's exact tests (FET) were used to determine if differences in self-reported behavior existed between the three groups.

4 RESULTS

4.1 Gamified climate change engagement literature (Publication I)

A systematic literature review of gamified interventions for climate change engagement was conducted to set the stage for this doctoral work. The primary goal was to understand the contexts, populations, designs, outcomes, and quality of the existing research in this area to propose an agenda for future research. Since its ambition was to bring together and deeply engage with the literature, the article was supplemented with openly accessible materials detailing all the data found and produced. The literature review answers the first research question of this dissertation:

> **RQ1:** What is the current scientific knowledge of gamified climate change engagement interventions?

The study gathered 64 empirical publications describing game-based and gamified interventions related to climate change engagement made available between the years 2011 and 2020, with a generally upwards trend in the number of publications across time. Therefore, the findings suggest that this area of research is nascent, growing, and typically inscribed in the environmental or the social sciences, based on the publication venues. Most importantly, the results of using gamified techniques for climate change engagement were generally positive across multiple contexts, populations, and design approaches.

In general, the review uncovered applications in varied contexts and for audiences ranging from students to local citizens and professionals (RQ1.1). In terms of approaches to climate change, a balance was found between engagement with climate science (n=29), mitigation (n=38), and adaptation (n=34), with multiple overlaps between them. The fact that 23 studies addressing mitigation and 11 about adaptation also included concepts of climate science is relevant, since underpinning climate action with a strong reasoning may support long-term and deeper engagement (Lorenzoni et al., 2007). There was also variety in the game formats found (RQ1.2), including digital (n=26 games) and analog (n=20) gamification, but also hybrid designs (n=21) including digital elements, usually simulations. This variety suggests an interest by researchers and designers to adapt to participants' preferences and contextual requirements, e.g., the use of digital approaches with young students or using role-plays complemented with simulations for professional contexts. The gamification designs used are also generally diverse, transcending in most cases the simple, and criticized, triad of points, badges, and leaderboards (Koivisto & Hamari, 2019). Achievement-like elements were present in all designs, and more than 75% included also at least one immersion and one social element.

Most findings in the reviewed studies suggested that gamification can have a positive impact in more than one dimension of climate change engagement, while providing satisfactory experiences for players (RQ1.3). Of the engagement dimensions, cognition seems to be the most studied (n=50), including knowledge about scientific aspects of climate change but also of adaptation and mitigation. Affect featured in fewer publications (n=24), and usually consisted of players' feelings towards their actions and climate change (e.g., interest, motivation, sense of empowerment, or responsibility). Behavior (n=35) is most typically found through in-game dialog, cooperation and competition, although some gamified interventions also resulted in personal and community-wide real-world behavior or the creation of outputs such as publicly available games and adaptation plans. The study also reviewed a subsample of articles (n=26) that included either before-after measurements or control groups, given their adequacy to answer efficacy questions. These studies also suggested that interventions often support experiential learning, provide safe social spaces, and support engagement with climate change visually, while being perceived as preferable and more motivating than other options.

Despite the generally positive findings, the review also found room for improvement in both design and research (RQ1.4). Regarding context, most research seemed to be done in Western countries such as the US and the Netherlands, and it makes sense that mitigation interventions would be conducted, e.g., within the countries where per capita emissions are higher, such as OECD countries (World Bank, n.d.). However, as developing areas are particularly at risk (IPCC, 2022a), adaptation interventions should focus on those areas as well as rich countries also facing climate-induced challenges, such as the Netherlands. Some limitations were also observed in the populations included, e.g., the lack of pre-intervention measurement of attitudes and knowledge, the focus on highly educated adults, and the framing of participants in conventional and rigid ways, such as simulated decision-makers, consumers, or professionals.

As for the interventions themselves, they are often short, neglecting the learning potential of longer contact with games (Wouters et al., 2013), and focus on a few elements of climate change, including climate science, impacts such as droughts and floods, the costs and benefits of mitigation. Most behavioral outcomes observed occurred inside of games, with no direct impact outside of the fictional context, and in terms of experience it was observed that players may criticize games as too playful for professional settings, too complex, or not appropriate for them as an audience.

As a result of the gaps and opportunities found, the literature review proposes a series of agenda points for the advancement of the field of gamified climate change engagement. First, regarding contexts and populations (RQ1.1), the review recommends involving more social, political and economic actors as participants in gamified interventions; collecting more background information, including climate change engagement- and game-relevant aspects; involving emerging and developing economies, including institutions and scientists and participants; and conduct more research with K-12 students. Second, for systems content and design (RQ1.2), it is suggested that specific pro-environmental behaviors should be explicitly connected with climate change; in-game actions could be designed so that they have a direct impact in the real world; extending game-based interventions in time and combining them with other methods; and exploring climate change consequences beyond the most usually discussed. Third, and about the engagement results found (RQ1.3), the review calls for more careful measurement of behavioral outcomes, and for longer data collection. Fourth, to increase research quality and strength (RQ1.4), the review calls for more rigorous data collection and analysis methods and reporting, with controlled designs that include informational content as comparison and longitudinal research, and explicit consideration of ethical issues and good practices.

The gaps informing the following publications include the fact that players are often framed in ways that neglect rich citizen roles; the dearth of potentially useful frames such as health and wellbeing (Maibach et al., 2010; Myers et al., 2012; Walker et al., 2018); the limited exploration of direct behavior support through gameplay; and the need for rigorous controlled experimental research. The systematic literature review provided a few publicly available games that were analyzed as part of Publication II, as well as insights that informed the artifact and research design leading to Publications III-V.

4.2 Identities and actions in climate change games (Publication II)

Parallel to the lack of knowledge of the existing literature, knowledge of player identity and action in climate change games was missing from extant literature

(Katsaliaki & Mustafee, 2015; Knol & de Vries, 2011; Liarakou et al., 2012; Madani et al., 2017; Ouariachi et al., 2017a, 2017b, 2017c; Stanitsas et al., 2019). Publication II, then, examined existing digital climate change games (n=80) in search of insight on who players are and what they do in them. In a similar way to the literature review, the data collected and generated was shared openly as part of the supplemental materials accompanying the article. The game analysis publication answers the second research question in this dissertation:

RQ2: What is the state of the art of games that include climate action?

The main finding of this study is the classification of avatar identity types in climate change action games (RQ2.1), based on the norms that players are encouraged to follow and the final goals that they are presented with. The classification can be found in Table 7.

Table 7. Avatar identity types. This table appears in Publication II (work licensed under a Creative Commons Attribution International 4.0 License).

Group (n)	Norms	Goal
Climate self (9)	Real-world citizen-like behavior, including democratically available mechanisms.	Address real-world climate challenges.
Climate citizen (4)	Citizen-like behavior in a functional world, including democratically available mechanisms.	Address climate challenges in the game world.
Climate hero (21)	Access to specialized or superhuman means, focus on the individual agent's behavior.	Address climate challenges in the game world.
Empowered individual (3)	Combination of citizen-like norms, such as action through consumption, and specialized ones, such as goods production and political influence. The avatar is an individual agent but is encouraged to negotiate with others and to protect the environment, which is affected by player action.	Pursue individual and/or collective development, in some cases leading to victory over/with others.
Authority (34)	Specialized means giving large power over a collective or organization. The power is limited by multiple interests and/or environmental issues.	Pursue community or business development. In most cases, this requires directly addressing mitigation and/or adaptation challenges.
Faction leader (9)	Specialized means giving large power over a collective or organization. The power is limited by tensions with other leaders (addressed peacefully or not) and environmental issues.	Reach victory over/with similar external entities.

The article also examined climate action types in the games (RQ2.2), divided according to two issues (RQ2.3)—mitigation, when they aimed to reduce greenhouse gas emissions or concentrations, and adaptation, when they aimed to minimize climate risks and prepare for impacts. In terms of mitigation, a thematic analysis focusing on the skills and tools that avatar identities used led to the creation of seven categories of actions, found in 70 games in total: lifestyle, public participation, technology, energy, policymaking, nature-based solutions, and violence. Climate selves typically engaged with lifestyle actions; climate citizens practiced both lifestyle and public participation actions; climate heroes combined the previously mentioned actions with technological and energetic solutions promotion and implementation; empowered individuals presented a combination of individual and policy actions; and both authorities and faction leaders typically implemented technical, energy, and policy-related mitigation tools. Meanwhile, adaptation is represented in 34 games, and is mostly done by empowered individuals, authorities, and faction leaders.

In the games where players represented a climate self, citizen or hero, the goal (RQ2.4) was connected directly to a form of climate action; therefore, failing to successfully engage with these meant either not progressing, not finishing, or losing the game. In contrast, empowered individuals did not require sustainable action to win, although they were punished with climate impacts hindering goal achievement. Most authorities, 82%, tied victory to addressing climate change, although they had other tools at their disposal. Finally, faction leaders tended to have freedom in how they wanted to approach their strategies; while expansion was usually the road to victory, growth and development tended to increase global warming. The study also examined the spatial contexts in which actions take place. 36% of the 80 identities operated at the personal or household level, 42% locally, 44% regionally, and 52% globally. Half of them, 52%, combined at least two spatial scales, while 38% specifically combined personal or local with regional or global actions.

The findings of this study provided an understanding of the kinds of designs and player identities missing from existing games, so that not only a potentially beneficial but also new concept could be developed. Particularly, citizen-like identities were few and presented action types that were rather limited, typically including lifestyle actions and public participation. The findings also suggest that immersive VR is rare in existing publicly available climate change games, as previous literature had also found (Fernández Galeote & Hamari, 2021). While the scarcity of studies should not be surprising given that this is an emergent technology, its engagement potential (Breves & Greussing, 2021; Li et al., 2020) added to the reasons to create a novel design compatible with this technology. In addition, a scarcity of serious games involving gamified action was observed, which contributed to the hybrid design idea of combining in-game content with customized climate change action suggestions, which are closer to the traditional understanding of gamification for behavior change. The resulting artifact is the game used in publications III-V.

4.3 Player experiences (Publication III)

Publication III followed the creation of a game, *Climate Connected: Outbreak*, based on recommendations and gaps found in Publications I and II, and aimed to study the serious game player's experience in its complexity. In contrast with existing frameworks focusing on game elements that support learning, the focus here was on player actions and explanations to acquire a more nuanced understanding of the effects of the climate change serious game used. Publication III answered the third research question of this dissertation:

RQ3: How do players experience and interact with a climate change game designed from and for research?

The thematic analysis of the data surfaced four themes, including continuity, discontinuity, divergence, and topic engagement, each of which containing subthemes and categories. Continuity (RQ3.1) includes events and aspects of the experience indicating player progress according to the designer's expectations; discontinuity (RQ3.2) comprises interruptions and frustrations in said progress; divergence (RQ3.3) includes departures from the designed path that do not constitute interruptions and frustrations; topic engagement (RQ3.4) comprises moments of climate change engagement, whether in the game or in their personal life. Aspects of the emotional experience and events related to aspects of the game were also included as part of each theme (e.g., representation elements that resulted in topic engagement; emotions felt in relation to divergence). The four themes, the 15 subthemes and the 43 categories can be seen in Table 8.

Table 8. Results of the thematic analysis, including themes, subthemes, and categories. This table appears in Publication III (work licensed under a Creative Commons Attribution International 4.0 License).

Theme	Subtheme	Categories
Continuity	Goal preparation	Reading instructions; Methodical exploration; Reasoned or clearly prompted exploration

Theme	Subtheme	Categories
	Goal attainment	Purposeful but spontaneous goal attainment; Purposeful and reflective goal attainment; Excess in goal attainment
	Design-enabled player failure	Failure due to lack of attention; Failure due to lack of knowledge
	Evaluations and emotions supporting continuity	Evaluations of representation contributing to continuity; Emotional continuity
Discontinuity	Limited goal preparation	Lack of visual guidance; Lack of textual guidance; Missing information with a negative experience impact; Missing information with no serious consequence; Aimless exploration after lacking information; Aimless exploration despite a reasoned or clearly prompted task; Aimless exploration that gets resolved by chance
	Goal-related discontinuities	Failed premature goal-directed action; Unsupported goal-directed action; Accidental or thoughtless goal achievement
	Unintended failure	Technical failures; Anticipating failure
	Psychological and physical resistance	Resistance to engage; Player limitations affecting game reception
	Evaluations and emotions related to discontinuity	Evaluations of representation contributing to discontinuity; Emotional discontinuity
Divergence	Divergent behavior	Divergence with creatures and characters; Environmental divergence; Failing on purpose to see the consequences
	Humorous comments	Humorous comments about the environment; Humorous comments about creatures and characters; Humorous comments about information
Topic engagement	Engaging with new information	Learning; Doubts and misunderstandings
	Connecting information to the past and future	Limited learning; Knowledge of oneself and one's action; Knowledge and perception of the world; Effect on intention and future ideas; No change in intention
	Teaching the game	Criticism of the content; Criticism of the medium
	Topic-related evaluations and emotions	Evaluations of representation strengthening topic engagement; Emotional topic engagement

According to the results, the designers' goals of promoting a specific game experience are supported by multiple elements, but continuity (RQ3.1) was not always as expected. Sometimes players were able to fulfill a goal but engaged in unnecessary actions as part of it; sometimes failure afforded by the design occurred not because a challenge was too difficult, but because instructions were ignored or forgotten. In addition, it was found that players may accept aspects that they would consider negative in games for entertainment, such as large amounts of text or lack of polish, which suggests that they framed the experience not as any other game, but as a learning artifact and a work-in-progress research artifact. Therefore, although players may expect a playful experience based on their previous interactions with video games, they may also partially reframe their expectations based on context.

Discontinuity instances (RQ3.2) yielded findings such as moral resistance to participating in certain activities in the game, or interferences caused by illness or forms of physical discomfort such as motion sickness, which limit some players' engagement with digital games. Another participant felt quickly overwhelmed by the content, to the point that he repeated that he would not be able to remember it despite not having been told that he was expected to do so, and it was also said that complicated expressions interrupted the flow of play, which reinforces the importance of using everyday language (Mayer, 2005). It was also observed that players may progress in the game without correctly interpreting what their actions mean, which is an undesirable outcome from the design standpoint. Since persuasive play often relies heavily on interaction (Antle et al., 2014), the fact that progress does not always equal learning (Linderoth, 2012) implies that explicit clarification may be needed for central ideas to be understood. Ambiguous moments were also recorded, when it was not clear whether the game was failing at guiding players or were they at fault for not paying attention.

The findings also include moments of divergence (RQ3.3), when the experience could not be completely authored and players showed that they wanted to do more than learning. They engaged in actions that did not align with game expectations, such as talking to characters or attempting to interact with elements in ways that were not supported (e.g., soaking them with a hose). They also expressed their wish for more playful interactions and free exploration, a recognized motivation in gamification (Tondello et al., 2016). Rather than assuming that this kind of unexpected behavior would not occur in more open settings, the opposite may be true—although no participants exhibited behavior attempting to disrupt or break the system, this is a motivation for some players (Tondello et al., 2016).

The participants' topic engagement (RQ3.4) was sometimes unexpected, too. Cognitively, players generally expressed already being familiar with the climate change elements depicted in the game, but they did recognize new connections between them. Therefore, as a learning experience, the game succeeded more as a systems thinking reinforcement than as a pedagogical, fact-based instrument. In fact, players displayed autonomous or agentic forms of learning (Reeve & Tseng, 2011), such as reaching conclusions based on the integration between the game content and their pre-existing knowledge and ideas. For example, one participant suggested insect-based diets as a low-carbon option, which was not discussed at all in the game, and contradictions in the game were sometimes commented on. At the same time, some players tended to take examples as the most relevant exponents of an issue, which was not always the case, e.g., when showing a video game console to discuss energy consumption. Designers should be aware of these issues, and make sure that the examples chosen are intentional.

In terms of affect, participants displayed complex emotional responses to climate change, both within the game and in relation to their perceptions of the state of the world. Thus, the game acted as a reminder and a prompt for discussion. In contrast, the game had a limited use in supporting pro-environmental intention change through a didactic approach, as discussed in the literature (Antle et al., 2014; Whitmarsh et al., 2015). Multiple participants mentioned acting pro-environmentally already and lamented that the game did not provide them with new insights. The fact that the game did propose some forms of action, but they were not explicitly asked of the players, may indicate that serious games aiming to behaviorally engage should present action explicitly and in a tailored manner. Therefore, the unusual framing—the health and well-being impacts of climate change—and the new connections discovered did not necessarily translate into behavioral change. Thus, designers could focus on directly facilitating climate action at the required scale, with a deep understanding of what barriers and issues, as well as facilitators, citizens find in it, combining the provision of engagement opportunities and respect for autonomy.

4.4 Learning effects (Publication IV)

Publication IV uses a more developed and multi-platform version of *Climate Connected: Outbreak*. Continuing with the design inspired by climate change engagement literature and the gaps and recommendations found in Publications I and II, it includes a health and wellbeing frame, a complex and open understanding of the citizen's identity towards climate change, and an immersive VR version. Considering the lack of rigorous experimental designs with informational control conditions in research, the study described in this publication compares the game in immersive VR and PC screen with a text-based control to answer the fourth research question:

> **RQ4:** What are the learning effects of a climate change game designed from and for research?

The descriptive statistics for each group before and after the intervention can be found in Table 9 and visualized in Figure 9. As in previous studies in this dissertation, the quantitative data relevant to this study was shared openly with the article. To answer RQ4.1, repeated measures ANOVA found that the number of correct answers increased significantly from before (M=9.22, SE=.21) to after the treatment (M=11.5, SE=.16), F (1, 102)=156.04, $p < .001$, $\eta 2G$=.269, $\eta 2$=.266 (large effect (Cohen, 1988)), $\eta 2p$=0.605. However, no statistically significant difference between groups was detected (F(2, 102)=0.654, p=0.522) (RQ4.2).

In terms of the within-subjects part (RQ4.1), a Wilcoxon rank test corroborated the significant difference between correct answers before (M=9.22; Mdn=9; SD=2.12) and after (M=11.5; Mdn=12; SD=1.65); [W=39, $p < .001$, d=0.98 (large effect)]. Wilcoxon rank tests also suggested significant differences in the control group between before (M=9.66; Mdn=10; SD=2.21) and after (M=11.6; Mdn=12; SD=1.67); [W=9, $p < .001$, d=0.952 (large effect)]; in the PC group between before (M=9; Mdn=9; SD=2.17) and after (M=11.5; Mdn=12; SD=1.60); [W=0, $p < .001$, d=1 (large effect)]; and in the VR group between before (M=9; Mdn=9; SD=1.96) and after (M=11.4; Mdn=12; SD=1.73); [W=6, $p < .001$, d=0.976 (large effect)].

For the between-subjects part (RQ4.2), a non-parametric analysis of covariance (ANCOVA) did not find a statistically significant difference between groups in correct answers after the treatment, T=0.025, p=0.970.

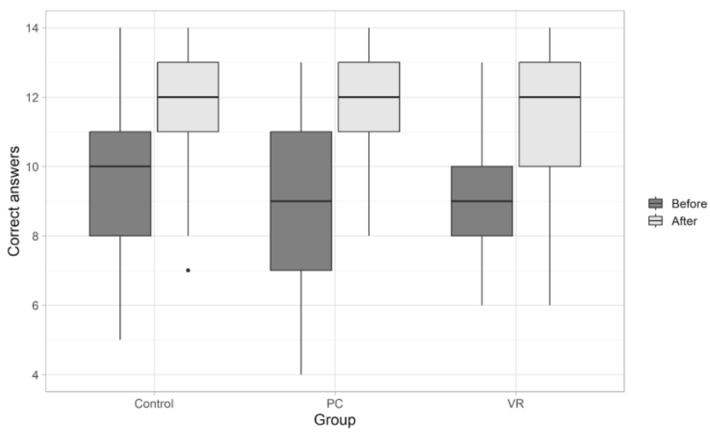
Therefore, the null hypothesis "$H_{0.1}$: There is no significant difference between pre- and post- intervention performance" was rejected based on the within-subjects part of the repeated measures ANOVA and the Wilcoxon rank test, which suggested that the intervention had a large positive effect on the learning outcomes. However, the null hypothesis "$H_{0.2}$: There is no significant difference in post-intervention performance between text readers, PC players, and immersive VR players" could not be rejected based on the between-subjects part of the repeated measures ANOVA and the non-parametric ANCOVA.

With the data classified in two groups, control (n=35) and game (n=70, PC and VR together), a repeated measures ANOVA was conducted, complementing the answer to RQ4.2 above. The test did not find any between-subjects effects, $F(1, 103)=1.27$, $p=0.262$, and neither did a non-parametric ANCOVA controlling for the participants' initial knowledge, $T=1.195$, $p=0.587$. Hence, the null hypothesis "$H_{0.3}$: There is no significant difference in post-intervention performance between text readers and game players" was not rejected. Thus, the results of this study suggest that a game with the characteristics described, played by an audience similar to the sample above, can lead to similar immediate knowledge gains as a text with graphs.

Table 9. Participants' performance per group, before and after. For each moment, the table includes the correct answers' mean (M) and standard deviation (SD); correct, incorrect, and "don't know" (NA) answers; and pre- vs. post-test change. This table appears in Publication IV (work licensed under a Creative Commons Attribution International 4.0 License).

Group	N	Pre-test					Post-test				
		M	SD	Correct	Incorrect	NA	M	SD	Correct	Incorrect	NA
Control	35	9.66	2.21	338	59	93	11.6	1.67	405 +19.82%	61 +3.39%	24 -74.19%
PC	35	9	2.17	315	62	113	11.5	1.6	404 +28.25%	63 +1.61%	23 -79.65%
VR	35	9	1.96	315	80	95	11.4	1.73	398 +26.35%	78 -2.5%	14 -85.26%

Figure 9. Participant scores per group, before and after the intervention. The lines indicate that all median values increased (12, up from 9 and 10). This figure appears in Publication IV (work licensed under a Creative Commons Attribution International 4.0 License).



A descriptive observation of the answers revealed that, of 1470 pairs of responses (14 questions times 105 participants), 19.3% improved, 74.3% remained the same, and 6.4% worsened, based on a categorization in which correct is better than NA and NA is better than incorrect. All conditions were similar in terms of improvement, permanence, and worsening (control: 16.5%, 78%, 5.5%; PC: 21.2%, 72.7%, 6.1%; VR: 20.2%, 72.2%, 7.6%). While PC and VR players improved their responses to a larger degree than readers, their answers were less accurate before the treatment, while the number of correct answers post-treatment was almost identical (see Table 8). Most positive changes were from NA to correct (74.5% of positive change) and most negative changes were from NA to wrong (59.6% of negative change). This was true for all three conditions. Uncertainty was resolved mostly positively (203 changes NA-correct) but not always (56 NA-incorrect).

The descriptive observation of the data and the ways in which the question-relevant content was presented in the stimuli also suggested a series of design recommendations (RQ4.3). These include reinforcing messages with visualization and interactions; focusing on the most important messages, such as common misconceptions, for alignment with visuals and actions, since centering the action around a trivial part of an issue may detract attention or even appear to contradict its core aspects; showing the message's implications clearly, explicitly, and impactfully; requiring attention to progress, ideally integrating actions that demonstrate understanding within the gameplay loop; and paying attention to the effects of gameplay over time, including tiredness after extended immersive VR use.

4.5 Attitude, self-efficacy, and behavior effects (Publication V)

Like Publication IV, this article focuses on the experimental study comparing immersive VR, screen-based PC game, and text. However, instead of learning, the article examines the results involving climate change attitudes, environmental self-efficacy, PEI, and PEB, as well as two aspects of the gameplay experience: interest/enjoyment and immersion. Thus, Publication V aims to answer the fifth question of this dissertation:

RQ5: What are the effects on key engagement indicators of a climate change game designed from and for research?

This question was articulated through several hypotheses and research questions, whose methods and outcomes can also be seen in Table 10.

Table 10. Summary of hypotheses and research questions, including the statistical tests used, if any, and the outcome. A modified version of this table appears in Publication V (work licensed under a Creative Commons Attribution International 4.0 License).

	Hypothesis or research question	Statistical test	Outcome
H1.1	Playing the game in any form will be significantly more enjoyable than reading the text.	Kruskal-Wallis & Dwass-Steel-Crichtlow- Fligner	Partially supported
H1.2	Playing the game in VR will be significantly more enjoyable than playing on PC.		Supported
H2	Technological immersiveness will be positively associated with self-reported immersion.	One-way ANOVA	Not supported
H3.1	The intervention in any of its forms will positively affect participants' climate change attitude.	Wilcoxon signed-rank	Supported
H3.2	The game-based conditions will result in a larger climate change attitude shift than reading the text.	Kruskal-Wallis	Not supported
H3.3	Technological immersiveness will be positively associated with a shift in climate change attitude.		Not supported
H3.4	Self-reported immersion will be positively associated with a shift in climate change attitude.	Spearman's rank correlation coefficient	Not supported
H4.1	The intervention in any of its forms will positively affect participants' environmental self-efficacy.	Wilcoxon signed-rank	Supported
H4.2	The game-based conditions will result in a larger environmental self-efficacy shift than reading the text.	Kruskal-Wallis	Not supported
H4.3	Self-reported immersion will be positively associated with a shift in environmental self-efficacy.	Spearman's rank correlation coefficient	Not supported
RQ1	How are the climate change attitudes and environmental self-efficacy data distributed in terms of interest/enjoyment?	NA (visual examination)	No apparent correlations observed

	Hypothesis or research question	Statistical test	Outcome
RQ2	What PEIs and PEBs can be observed as a result of the intervention?	χ^2 tests of independence and FET	Almost all participants signaled PEI; no statistical differences in self-reported PEB between groups

To test the ENJOYMENT-related hypotheses (H1.1 and H1.2), a Kruskal-Wallis test was conducted. Significant differences were found between the groups, H(2)=17.40, p < .001. Post-hoc Dwass-Steel-Crichtlow-Fligner pairwise comparisons suggest that VR users reported significantly higher enjoyment than PC users (W=3.66, p=0.026, δ=0.359) and text readers (W=5.60, p < .001, δ=0.549), suggesting medium and high effect sizes, respectively (IIPUS, n.d.). The difference between PC players and text readers was non-significant, W=2.72, p=0.132.

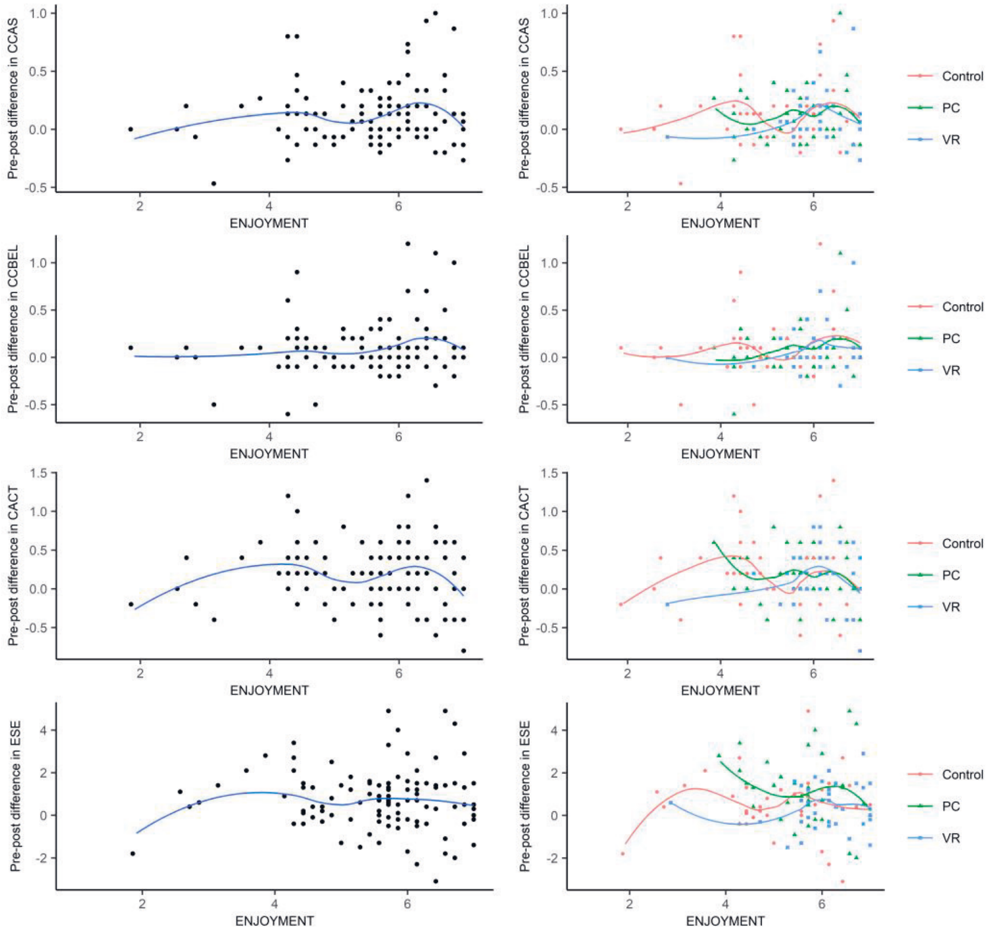
To test H2, which posits that the participants' IMMERSION will mirror technological immersiveness, a one-way ANOVA was performed. No significant difference was found between the three groups, F(2, 67.5)=0.848, p=0.433, although the mean was higher in the game groups (PC=5.03, VR=5) than in the control (4.76).

Hypotheses 3.1 through 3.4 referred to climate change attitudes, operationalized through the CCAS scale and the CCBEL and CACT constructs. Wilcoxon signed-rank tests (one-tailed) revealed a statistically significant increase in the participants' CCAS, CCBEL, and CACT after the intervention for all three groups: control (CCAS: Z=85, p=.002, r=0.609; CCBEL: Z=94.5, p=.011, r=0.500; CACT: Z=91, p=.005, r=0.552), PC (CCAS: Z=87.5, p < .001, r=0.647; CCBEL: Z=82, p=.015, r=0.495; CACT: Z=61, p=.003, r=0.625), and VR (CCAS: Z=69, p=.003, r=0.607; CCBEL: Z=62.5, p=.011, r=0.547; CACT: Z=99, p=.026, r=0.436). To examine possible differences between the groups, an analysis of variance was done on the participants' attitudinal shift (post - pre). A Kruskal-Wallis test found no significant differences in shift for CCAS (H(2)=0.209, p=0.901), CCBEL (H(2)=0.041, p=0.980) or CACT (H(2)=0.762, p=0.683). Finally, neither visual exploration of the data nor Spearman's rank correlation coefficient tests suggested a significant correlation between IMMERSION and CCAS, CCBEL, or CACT.

Hypotheses 4.1 through 4.3 involved environmental self-efficacy, measured through the ESE-10 instrument. Wilcoxon signed-rank tests (one-tailed) showed a significant difference in the pre-post comparison for each of the three groups—control (Z=150.5, p =.010, r=0.463), PC (Z=81, p < .001, r=0.728), and VR (Z=161.5, p=.010, r=0.457). However, an analysis of variance on the pre-post change in ESE using a Kruskal-Wallis test found no significant differences in ESE shift between treatment groups (H(2)=4.06, p=0.131). As with climate change attitudes, neither visual exploration of the data nor Spearman's rank correlation coefficient tests suggested a significant correlation between IMMERSION and ESE.

To answer this study's RQ1 (not to be confused with this dissertation's RQ1), attitudes and self-efficacy were explored in relation to interest/enjoyment through data visualizations. No consistent patterns were discerned when plotting ENJOYMENT against CCAS, CCBEL, CACT, or ESE (post - pre) (see Figure 10).

Figure 10. Changes in CCAS, CCBEL, CACT and ESE based on self-reported ENJOYMENT for all participants (left) and divided by treatment group (right). This figure appears in Publication V (work licensed under a Creative Commons Attribution International 4.0 License).



Finally, the study included an observation of participants' PEI and PEB to answer its RQ2 (not to be confused with the dissertation's own RQ2). Of the 105 participants, 102 participants (all who played the games and 32 of the 35 who read the text) indicated interest in engaging in climate action. A FET did not find significant differences between the three groups (p=.105). These participants received an email with information according to their chosen preferences. Then, 10 days after participating in the experiment, they were sent a follow-up questionnaire, which 42 participants answered (control: 14; PC: 13; VR: 15). The results can be seen in Table 11. χ^2 tests of independence and FET performed for each of the six response variables (the action was done; steps were taken towards it; will do the action in the future; the action was not done; the action was forgotten; the intervention has inspired the participant to engage in further climate action) suggest that there are no significant differences between the three groups.

Table 11. Self-reported participant climate action completion after the experiment. This table appears in Publication V (work licensed under a Creative Commons Attribution International 4.0 License).

Group	Done	Steps	Future	No	Forgot	Inspired
Control	6	3	4	1	0	11
PC	3	4	3	1	2	11
VR	6	2	5	1	1	12
Total	15	9	12	3	3	34

5 DISCUSSION

This dissertation aimed to *understand the current situation of gamified climate change engagement (extant science and designs), to develop a climate change game designed following best practices, and to assess its cognitive, affective, and behavioral engagement effects.*

For this purpose, it compiled and critically examined the scientific understanding of gamified climate change engagement and publicly available digital games, and used an original multi-platform digital climate change game to examine the experiences and outcomes of its use in empirical studies. Thus, the dissertation included a systematic literature review (Publication I), a qualitative content analysis of digital climate change games (Publication II), and three publications using the novel artifact created, including a user study (Publication III) and quantitative analyses of learning (Publication IV) and climate change attitudes, environmental self-efficacy, PEI and PEB (Publication V). Their findings have been outlined and shortly discussed based on the research questions presented in Section 1.1:

RQ1: What is the current scientific knowledge of gamified climate change engagement interventions?

RQ2: What is the state of the art of games that include climate action?

RQ3: How do players experience and interact with a climate change game designed from and for research?

RQ4: What are the learning effects of a climate change game designed from and for research?

RQ5: What are the effects on key engagement indicators of a climate change game designed from and for research?

By answering these questions and their sub-questions where applicable, the dissertation provides a holistic perspective of gamified climate change engagement. Its study objects are scientific literature, games, and players. Accordingly, the practices engaged with include knowledge assimilation and synthesis, scholarly play, design practice, and empirical examination of experience and effects. These practices have been encapsulated in methods that include a systematic literature review, qualitative content analysis of artifacts and human experiences, and quantitative descriptive and inferential examination of effects. By combining a broad focus on literature and games and empirical interventions with a particular design, this dissertation contributes both to a broad understanding of the general landscape and a deep comprehension of the possible climate change and game engagement outcomes of using serious games in this area. In these ways, which combine climate change engagement with the research and practice of gamification, the dissertation is aligned with the critical realist perspective and its call for interdisciplinarity in climate change research (Bhaskar et al., 2010).

Taken together, the findings suggest that gamified climate engagement is a nascent area of inquiry with significant potential given (a) generally positive findings in the literature across a variety of contexts, audiences and designs (RQ1) and (b) considerable variety in the ways in which digital climate change games invite players to engage with relevant phenomena, with identities ranging from themselves or fictional citizens to heroes, empowered individuals, authorities, and faction leaders (RQ2). However, as discovered when answering RQ1 and RQ2, the field presents significant gaps in terms of existing game and research designs. The empirical research presented here suggests that player experiences with climate change games are more complex than usually assumed by comprising various forms of compliance and resistance, including diverse ways of cognitively and affectively processing content (RQ3). Furthermore, while effective in promoting climate change learning (RQ4), attitudes, self-efficacy, and action (RQ5), their advantage over more traditional media may not be evident, at least given the specific contexts, populations, and designs used in the empirical research presented here (RQ4 and RQ5).

The findings above provide suitable discussion points for each of the three dimensions of climate change engagement, i.e., cognitive, affective, and behavioral, as well as for the player experience as a fourth concept of interest. Considering first **gamified climate change engagement as a holistic concept**, Publication I uncovered effects promoting all types of engagement in existing interventions, in addition to generally positive game experiences. However, some interventions were found to lack elements that would help appropriately support and contextualize their findings. These include limited understandings of participants' identity and possibilities in relation to climate change and environmental sustainability, and a lack of rigorous data collection, analysis methods, and controlled research designs including informational control treatments (Soekarjo & Van Oostendorp, 2015). In a similarly holistic way, the analysis of avatar identities in Publication II revealed potential to support all three dimensions of climate change engagement at once through desirable and diverse goals, norms, and courses of action. This was done either by resembling players and thus allowing them to learn what to do and how to do it, or by providing emotional engagement with characters, actions, and results not necessarily similar to their current personal relationship with climate change. However, an imbalance was found in the number of games, with few representations of citizens and empowered individuals especially.

The player experiences described in Publication III similarly offer insight into the ways in which gameplay relates to cognitive, affective, and behavioral climate change engagement in ways that are not necessarily isolated, as game situations can concurrently elicit moments of realization, emotional responses, and reflections upon past and future personal action. Based on the richness of experiences observed, the diversity of potential players, and their desire to relate to games in their own terms, I suggest that existing game-based learning design frameworks could be expanded beyond the need to painstakingly author learning outcomes, feelings (e.g., Argasiński & Węgrzyn, 2019), and enjoyment (e.g., Ferreira de Almeida & dos Santos Machado, 2021). The main reason is that designers cannot predict a player's every thought, feeling, and action, not to mention their previous experience with a topic.

Aiming to assess further linkages between experience and climate change engagement outcomes, Publication V revealed that for the game used, neither immersion nor enjoyment seemed to correlate with other variables of interest. This questions some of the potentials usually attributed to immersive media (Breves & Greussing, 2021) and suggests the importance of more research avoiding the pitfalls mentioned in Publication I to provide high quality evidence.

I turn now to each of the four topics of interest, that is, the three climate change engagement dimensions and the game experience. In **cognitive** terms, most of the studies examined in Publication I focused on knowledge acquisition, in line with previous studies (Rajanen & Rajanen, 2019). However, more topics and frames could be explored. Some interventions could also be designed to be more persistent, which would not only connect them to the audiences' habits and routines but also increase their learning potential (Wouters et al., 2013). To challenge the prevalence of isolated cognitive outcomes in the literature, Publication III deviated from an understanding of the learning experience that privileges information acquisition while ignoring other aspects of it. The findings support a complex understanding of the player's cognition while playing a serious game like *Climate Connected: Outbreak*, where insights are contextualized based on previous understandings and experiences. Based on expressed and enacted player preferences, the findings also support the exploration of agency as a valuable ingredient in game-based learning, in line with existing educational concepts such as agentic engagement (Reeve & Tseng, 2011).

Having applied to the game's design some of the insights collected in the user study, Publication IV compared *Climate Connected: Outbreak* to an informational control to reveal that, while the design used resulted in large knowledge gains, there were no significant differences between immersive VR, PC, and text. This study provided four possible aspects that may have limited the game's comparative effectiveness: (a) the text, whose graphics and narrative may have made it reasonably engaging, (b) the game, which was largely text-based due to the need to be comparable with the control treatment, and some of whose elements could have distracted players from the main learning content rather than reinforcing it (Parong & Mayer., 2018), (c) the questionnaire, which was an immediate and short way of assessing knowledge but which is insufficient to capture nuanced or long-term understanding; and (d) the fact that participants were so voluntarily and it is reasonable to assume a degree of interest in the topic in many of them irrespective of the compensation received.

While Publication IV does not claim to offer a definitive answer to the question of how effective games and gamified immersive technologies are in promoting cognitive climate change engagement, the game and study design add to the evidence in this regard, and in some ways constitute a unique intervention which will hopefully be followed by others soon. To aid in future designs, the study provides recommendations for VR and game-based learning of climate change based on the observed effects of various parts of the game. These recommendations can be summarized as focusing on key issues, such as misconceptions, in ways that are visual, impactful, interactive, and meaningful for game progress.

Affectively, and despite the smaller number of studies examining this type of outcome, Publication I shows a diversity in emotional outcomes, mostly focused on the individual's role and actions, from feelings of motivation and responsibility to empowerment and a sense of importance connected to personal pro-environmental behavior. However, not every form of affect felt in relation to gamified climate change engagement is positive. For example, excessive game difficulty may lead to fatalism (Waddington & Fennewald, 2018). The complexity of emotional engagement with climate change and games was further explored in Publication III, including both positive and negative emotions felt in relation to gameplay and other emotions felt in relation to climate change, clustered around frustration and disappointment; sadness, concern and overwhelm; and surprise and curiosity. Thus, the emotions observed towards climate change are consistent with some of the ones observed in the psychological literature (Pihkala, 2022), but games add an additional layer of experience that may be occurring at the same time, e.g., with the player enjoying the interactions in a minigame while being reminded of their negative emotions towards the topic.

The study described in Publication V examined attitudinal change, understood as a function of beliefs, affect and intentions (Schultz et al., 2005). It showed climate change attitude gains, but no significant differences between immersive VR, PC, and illustrated text. The same occurred with environmental self-efficacy, a concept linked with confidence (Moeller & Stahlmann, 2019) and thus with affect, but also related to knowledge and behavior. It should be noted that the participants' climate change attitudes were generally high before the intervention, with a median of 4.6 out of 5, and again the similarities between text and game may have played a role in the lack of difference between groups. Because the sample may have been already interested in the topic, even those who did not feel high levels of enjoyment or immersion with the game or text may have still paid attention and put effort in the experiment. Turning to self-efficacy, with a median rising from 6.6 to 7.4/10, similar explanations can be offered. Because the game included a large degree of text-based encouragement and in most cases did not pursue extensive action-oriented behavioral learning, there is still room for using interactive media to affect self-efficacy in a more direct way. This could be done with artifacts that focus on capacity-building and skill development rather than dedicating most of their time to show systemic issues, as *Climate Connected: Outbreak* does.

In **behavioral** terms, actions examined in the literature (Publication I) typically occurred in-game, which does not imply an automatic translation into real-world action. Furthermore, in-game actions need not be particularly varied. When the games analyzed in Publication II presented identities close to the average citizen's, their action types were rather limited, typically including lifestyle choices and public participation. In contrast, the study reported in Publication III found diverse forms of behavioral player engagement, including effects on intentions and future ideas such as lifestyle changes and career choices to increase public influence, such as engaging in politics. Still, in other cases the lack of new ideas, psychological barriers or inconvenience of climate action resulted in no change in intentions, which is in line with previous research discussing the importance of barriers (Gifford, 2011; Lorenzoni et al., 2007) and the limitations of pedagogical approaches for behavior change (Antle et al., 2014). These results suggest that game-based learning design can pursue outcomes beyond only learning, as is typical in existing frameworks (e.g., Arnab et al., 2015), and consider games' implications in learners' lives. Despite the rich interactions between serious game play and behavioral implications observed in Publication III, the examination of PEI and PEB as part of Publication V showed positive signs but no clear differences between the game and the text. This suggests that the approaches may have been perceived as too alike to result in different outcomes, which opens the door to future studies that directly encourage players to act on climate change through different game designs, e.g., with multiple players and in genres other than narrative puzzle adventure.

In addition to climate change engagement constructs, the involvement of gamification as the other major element in this dissertation motivates the inclusion of aspects related to the **game experience**. Gamification was defined through a broad lens (Hamari, 2019), which allowed to include both digital and analog interventions, for behavioral and cognitive change alike, and irrespective of whether they were framed as standalone games, gamified layers on top of existing systems such as courses, or even playful interventions such as role-plays, interactive exhibitions, and game jams. The broad understanding of the concept also allowed to create an artifact which combines elements of game-based learning and of direct behavioral support. The review of the literature (Publication I) uncovered that participants tended to prefer and enjoy gamified interventions, and to participate with a high degree of involvement. However, issues were also found, including the criticism of using games for serious purposes; problems with graphics, mechanics, and technical problems; and inadequacies in how content is (not) scaffolded.

The user study conducted as part of Publication III provided a further look into the complexity of the serious game player experience, showing various ways in which players navigate between what they expect from any digital game and the framing of serious games as educational interventions. In line with the expectations generated by Publication I, Publication V showed that the game, and significantly the VR version, was generally perceived as more interesting/enjoyable than the text. However, PC players did not find the game significantly more enjoyable than readers did the text, which is not necessarily surprising (Wouters et al., 2013) and can be explained by the engaging characteristics of the text, the relative lack of novelty of playing a PC game, the willingness of the participants to engage with the topic, and the university setting, with a sample that may have been generally used to reading.

Turning to the other game experience construct explored in Publication V, participants felt similarly immersed in all conditions, suggesting that using text as the primary form of communication may have made the game too similar to the control. The lack of significant differences in immersion may also be partially explained by the text having been comparatively engaging, since narratives can lead to transportation (Green, 2021) in a way that would have been detectable with the measurement instrument used. Once again, the results of Publication V, although representative only of certain contexts and design types, reinforce the need for rigorous research designs with informational control conditions in the future, which joins other implications which will be summarized next.

5.1 Implications

This dissertation contributes to the area of gamified climate change engagement in several ways—theoretically, practically, methodologically, and in bridging disparate fields. Theoretically, the work extends research done on **video game avatars and their identities** (Gee, 2008, 2014) to climate change games, providing a more complete understanding for further study and design practice and offering insights applicable to other problems and challenges sharing essential characteristics with climate change. The literature review uncovers various ways in which gamification contributes to, and hinders, **cognitive, affective, and behavioral engagement**, and provides a first approximation to the relationships between said outcomes and game design and format choices. These observations add to the broader insights provided by the climate change engagement scholarship (e.g., Lertzman, 2013; Monroe et al., 2019; Moser & Dilling, 2011; Sheppard, 2012; Whitmarsh et al., 2015; Wibeck, 2014), and those provided by previous reviews of the effects of gamification on climate change engagement (Flood et al., 2018; Rajanen & Rajanen, 2019).

Through empirical studies, the climate change engagement effects of a single-player narrative game are observed on a generally educated and concerned population, showing that in this case games can be as effective as more traditional media in promoting climate change engagement, but more research would help validate and understand these effects in more detail. The research done adds evidence to two different strands of research—**immersive media effects**, particularly in pro-environmental aspects (Breves & Greussing, 2021), and the realm of **gamification, serious games and game-based learning**, also for pro-environmental purposes (e.g., Soekarjo & Van Oostendorp, 2015).

The work done not only adds evidence, but it also pushes gamification techniques in two directions, bridging theory with practice. First, through Publication III, conceptualizing the player experience as consisting of continuity, discontinuity, divergence, and topic engagement, which goes beyond design as the practice of authoring an experience, and learning as the only yardstick. This is in line with **agentic** (Gee, 2003; Reeve & Tseng, 2011), **eudaimonic** (Deterding, 2014) **and punk** (Thibault, 2019) **engagement**. Second, through Publication IV, supporting the designer's agency as a crafter of effective messages, based on principles of **multimedia learning** (Barreda-Ángeles et al., 2021; Makransky et al., 2019), **embodied and grounded cognition** (Barsalou, 2008; Barsalou et al., 2003; Li et al., 2020), **educational visualization** (Chen & Gladding, 2014), **unlearning** (Nygren et al., 2017) by reframing pre-existing meanings, and attention to the affordances and limitations of **technology** (Knaack et al., 2019). Whether these are two divergent paths to effective education depending on the content, the audience and the context, or complementary, they represent two clear ways forward for investigating the potential of gamified cognitive engagement with climate change. Adopting a critical realist ethos, we should strive to explain reality as rigorously as possible through our social theories (Bhaskar, 2014), but multiple theories can be integrated to explain the same phenomenon without contradiction (Rousseau et al., 2008). This opens the door to future theoretical perspectives on gamified engagement that combine and assess the role of players' willingness to exercise their agency and the designers' interest to provide a streamlined and focused experience.

For the practice of gamification design and use in climate change engagement, the dissertation also identified multiple gaps and opportunities through the literature review, including **valuable but unconventional topics, frames, media, and research designs**. Similarly, the game analysis uncovered several **uses and applications** in both research—including questions for each identity type—and education—where the article provides a library of options that can be used not only for learning but also for discussion and criticism. In support of the sustainability argument by which avoiding unnecessary repetition is better, the evidence gathered contributes to the overall sustainability of the field. In addition, it detailed **approaches to climate change game design** that would be worth exploring—such as compensating for the dearth of climate citizens and empowered individuals in games, or creating more adaptation games from the citizen's viewpoint.

By providing **a game design example** aiming to merge the virtual and the real, learning and action, top-down and bottom-up, we encourage others to also consider the possible benefits and limitations of creating and using similar designs to ours with similar audiences and contexts, or to explore completely different approaches. Combining these practical contributions, the research done provides evidence of the state of the art of the literature and publicly available digital games, as well as new insight on the ways in which these games affect and are used by players, for others interested in regulating their use and promotion, e.g., policymakers and investors.

In methodological terms, the dissertation includes various methods and tools that future researchers can use, starting with the aforementioned **game design** combining aspects of serious gaming and gamification that are traditionally considered separate (Deterding et al., 2011; Landers, 2014; Plass et al., 2015), as well as an artifact that has been technically produced to be compatible with both traditional desktop screens and forms of control (i.e., mouse) and immersive VR. Apart from being an engagement method, the game was used for collection of self-reported data in the described **experiment design** (i.e., PEI), which is not a novel method (Frommel et al., 2015) but the limitations of which are still being explored (Gundry & Deterding, 2022). In addition to the game itself, the studies included in this dissertation provide a framework that can be used to analyze and create **climate change avatar identities and actions** in games (Publication II) which may have application outside of climate change games, for example in exploring wicked issues with multiple actors, causes, and consequences involved. Finally, a framework for analyzing **serious game player experiences** (Publication III) is provided, which may also be used for games about other topics than climate change.

As a fourth implication, this dissertation contributes to bridging the fields of environmental social science and games/gamification. The multidisciplinary approach adopted in this work combined perspectives from **the climate change engagement literature**—e.g., frame, message, medium; cognitive, affective, and behavioral engagement; knowledge types, attitudes, environmental self-efficacy, PEI, PEB—with those from **gamification and game-based learning**—e.g., game elements, the gameplay experience, enjoyment, immersion. Through the points of contact found, such as the importance of motivation, identity and context, but also having brought together apparently disparate ideas, I hope that future research in gamified climate change engagement continues to draw meaningfully from both worlds in accordance with their respective states of the art, and that curiosity is activated and collaborations sought between experts in both pillars.

Considered together, the publications in this dissertation provide the perspective necessary for researchers, designers, and educators to be more intentional in their study, creation, and use of gamification for engagement with climate change and other large, complex, and wicked sustainability issues. The picture that emerges implies that our current understanding and use show ample room for growth for two reasons. First, because the breadth of approaches is limited. Second, because a larger number of deep explorations of the topic—qualitatively, as in Publication III, or quantitatively, as in Publications IV and V—would surely reveal nuances to strengthen subsequent research and design approaches. Thus, applying intention in research, design and use means a willingness to rigorously explore promising or under-researched populations, contexts, game and research forms, and outcomes through a lens that considers all of them in their complexity.

5.2 Limitations

Despite the multiplicity of perspectives adopted and methods used in this dissertation, the work done is limited in several ways that should be acknowledged. A first limitation is the fact that the literature review was restricted to studies that mentioned climate change or closely related concepts. Although the focus of interest was climate change engagement, which presents unique challenges when compared to other ecological issues, there may be significant points in common and lessons to be considered in the literature about gamification of pro-environmental topics more broadly. In the opposite direction, the review of the literature presented in Publication I is diverse in regard to contexts, populations, and types of gamification, which resulted in an overview of the field that could be complemented by future reviews focused on specific questions and subsets of this reality. In addition, the forward publication search performed was not complemented with a backward one, given that it would have required a large amount of time and effort for uncertain results. The game analysis conducted and described in Publication II had a different set of limitations, of which two may be highlighted—the use of a single person's perspective for the analysis, and the fact that the resulting avatar identity classification is not completely unambiguous, given the presence of edge cases and mixed identities. However, the method followed, polythetic type-building, admits these possibilities, and the classification does not aim to be canonical and immutable.

The empirical research conducted with participants had its own limitations. These include the homogeneity of both samples, that of Publication III and the one described in Publications IV and V, since all were recruited around a university, Oulu in the first case and Tampere in the second. While participants in Oulu did not receive a material incentive for participating, experiment participants in Tampere received a movie ticket. For the quantitative studies, the sample included many highly educated young and middle-aged adults with considerable base knowledge of climate change. Similarly, the use of a distinct type of game designed explicitly for research should be considered as a limitation, given the variety of forms that gamification can take as seen in the literature review. In this case, the game was linear, story-based, typically lasted under one hour, prioritized simplicity of interaction, and focused on climate change. This is very different from, for example, analog multiplayer games where multiple strategies are possible and the outcomes are open-ended. While some findings may be extended to other games and contexts, others will not be. For example, the genre-typical forms of continuity observed in Publication III—i.e., exploring and finding objects. The study design was also limited in the sense that all groups were exposed to comparable conditions and were similarly prompted to engage in pro-environmental action, so no true baseline where no stimulus or commitment to act existed.

The use of a single-player serious game as the engagement mode in the empirical studies also poses other fundamental challenges. At its core, *Climate Connected: Outbreak* is an artifact focused on the player's individual experience and conceptualizes them as the channel through which climate action can occur. Whether the player's choices at the end have more individual or collective implications, it is the player who is centered as the actor who can change things, both in-game and out-of-game. While the central messages of the game reinforce the systemic aspects of the climate crisis and its countering measures, presenting climate change as a single-player adventure may help frame the issue as a journey that everyone should undertake by themselves. This caveat applies to similar gamified experiences, and to any engagement with the climate crisis framed as individualized.

Apart from the participants and the treatment conditions chosen, the measurement methods are also limited. For example, the participants did multiple tasks during the pre- and post-treatment data collection processes, which may have resulted in a degree of tiredness and prompted thoughts relevant to the knowledge test used for Publication IV. Variables such as learning were not measured longitudinally, so the effects of gaming and immersive VR cannot be assessed in terms of, e.g., knowledge retention. Focusing now on the variables studied in Publication V, it is likely that multiple aspects relevant to climate change attitudes and environmental self-efficacy, particularly in the participants' background and context, remain unknown (Kollmuss & Agyeman, 2002). Turning to PEB, the fact that it was self-reported introduces a degree of uncertainty—i.e., the assumption that those who did not answer did not act as a result of participating, and that those who replied were accurate. Of note is the fact that the sample size for the PEB data was much smaller than for the other variables, so those statistical results should be taken critically and will benefit from examination with larger samples.

As a global limitation, the critical realist perspective reminds us that our social reality is perpetually changing (Bhaskar, 2014). This means that the research undertaken will require further updates as climate change, and people's engagement with it, evolve. Similarly, the studies that systematically identify the existing literature and games will also need to be complemented with future research—regarding the literature, because this area of research keeps growing; regarding games, not only because new games continue to be released, but also because digital artifacts are prone to disappearing (Fernández Galeote & Hamari, 2021).

A different type of limitation refers to work that was not done but could be valuable in informing this perspective. For a more complete multidisciplinary study of gamified climate change engagement, the materiality of digital games is also important, given the social and environmental costs of the current model (Abraham, 2022; Huntemann & Aslinger, 2013; Mills et al., 2019; Perkins et al., 2014). Although multiple entities are developing and promoting a more sustainable digital games industry (Green Games Guide, 2023; PlayCreateGreen, n.d.; Playing for the Planet Alliance, n.d.; Project Drawdown, 2023b; Wood & Ruiz, 2021), more research is needed to understand digital gaming's impact and possible successful mitigation practices (Abraham, 2022).

5.3 Future research avenues

From the implications and limitations above, a wealth of future research avenues emerges along three axes: building knowledge, developing practice, and studying experiences and effects of gamified climate change engagement. To continue building knowledge, the first aspect to consider is that our understanding of this area is bound to remain relatively fleeting and in need of constant reassessment and restitching. This is true for climate change as a physically and socially mutating phenomenon, but also of gamification which is subject to similar social and technological forces. As said in the limitations, the provisionality of knowledge is true of both literature, with the state of research being constantly updated, and of games, which continue to appear and disappear as I write these lines.

To continue **developing our knowledge** of the literature, research should expand the focus to pro-environmental interventions even beyond the scientific literature and empirical studies, but also direct attention to specific phenomena, mitigation and adaptation responses, populations, and forms of climate change engagement for more specific insights (Flood et al., 2018). For quantitative insight, conducting meta-analyses to assess effectiveness would also be a valuable avenue.

To develop our knowledge of gamification in this area, scholars could similarly ponder the tradeoffs of adopting a wide lens encompassing disparate designs and formats versus diving deep into specific types of games and gamification. The study of games need not be limited to content analyses, either; digital ethnographies of player forums, for example, may offer insightful perspectives on player experiences of popular games, when adequately contextualized. Researchers are also invited to continue developing the work initiated in this dissertation regarding avatar identities in climate action games, especially in dialogue with the complex gameplay realities uncovered as part of Publication III. For example, they may examine these identities' potential further by studying how players interact with, adopt, and reject them.

Beyond what is being built, who is involved is also important. Gamified climate change engagement would benefit from the views of those who already live versions of a sustainable life so that their perspective can be playfully shared. For example, Indigenous Science and traditional ecological knowledge (TEK) has been recognized in sustainability for a long time (WCED, 1987). After all, and barring complexities that prevent drawing easy equivalences across disparate conditions, there is much to learn from and with those whose way of life has proven sustainable for human populations and their ecosystems (Ellis et al., 2021). Unfortunately, this cannot be said of the current hegemonic development model. As suggested in the literature review, partnerships with local peoples should be considered, especially in those places where climate impacts are most severe, which may include indigenous peoples whose local knowledge may surpass that of external researchers.

The second aspect after building knowledge is **developing practice**. The literature review, game analysis and empirical user research in this dissertation have provided various avenues for the future use of existing gamified approaches and the design of new ones, whether for research, for other utilitarian outcomes, or for entertainment. In a similar way to building knowledge with underrepresented sources, the creation of playful artifacts can offer a platform not only for education (Foltz et al., 2019; Puttick & Tucker-Raymond, 2018; Troiano et al., 2020; Tucker-Raymond et al., 2019) but also for the expression and sharing of indigenous cultures (Laiti et al., 2021; Steelman et al., 2019).

Another relevant practice aspect is the creation of *Climate Connected: Outbreak*, which remains one of the few climate change games available for immersive VR. As mentioned earlier, it can be found and downloaded for free online (Fernández Galeote et al., 2023a) and therefore used for any purpose. Educators or researchers willing to use the game in their practice should be aware that most participants needed very few instructions to use the game, as explained in Section 3.6.4. Despite the almost complete lack of usability issues during the experiment, participants were always monitored during gameplay. Regardless of the participants' assigned condition, researchers had a live video stream of their screens. Immersive VR players were able to ask any questions if they felt lost—although the game controls are simple and there is a clue system for finding objects, a few participants struggled with, e.g., placing a mosquito net, so they were given light advice. Educators may consider the convenience of debriefing the game to aid students to understand and relate to the content based on their learning objectives, curriculum, and teaching approaches. In any context, receiving information about action after the game based on player choice is an integral part of the experience. Therefore, researchers and educators should either pay attention to the players' choices as they occur or navigate the computer files to find the relevant log. All instructions and materials are provided with the game, including how to set it up for PC and Quest 2. The game can also be used independently in informal settings. Without the time pressure of an experiment or lesson, players may not require extra guidance, since the game is linear and moments of confusion tend to resolve quickly.

The game may be iterated upon and modified in the future. Given that the game uses some commercial assets that are not licensed for free distribution and use, researchers interested in access to the source code should contact me for possible collaboration projects involving modifications to the base structure of the game (e.g., to change its location or graphic style). They may also want to use the base design to create new artifacts that depart more clearly from the base game. For example, future spin-off modules may expose similar topics using a framing other than well-being. They may also expand on topics that the current game has only touched upon superficially, such as the historical, economic, and sociopolitical realities underpinning climate change, or zoom in on elements of the system shown in the game, for example the crucial aspect of land use. For new games deriving their design from that of *Outbreak*, similar mechanics may be used, including the combination of in-game and real-world action, which have led to significant learning, attitudinal, self-efficacy, and behavioral gains. However, it would be important to consider the improvements described at the end of Section 4.4.

Alternatively, researchers and educators may use existing games with similar characteristics for engagement. The supplemental files to Publication II include a list of the analyzed games, among which 13 resemble *Climate Connected: Outbreak* in the sense that they present a climate self or citizen identity. Beyond these, the similarity of other existing games with *Climate Connected: Outbreak* can be assessed using, e.g., Ouariachi et al.'s framework (2019); that is, games that show similarly achievable actions, a similar level of challenge, exhibit concrete and simple messages, present credible sources, aim to enhance efficacy through gameplay, are identity- and narrative-driven, present information as meaningful, and reward players for their actions. Some examples of such games, already categorized, can be found in the literature (Fernández Galeote & Hamari, 2021).

A third aspect in which to build future work, after building knowledge and developing practice, is **the study of experiences and effects**. First, multiple audiences would benefit from targeted research, including K-12 students, professionals whose activity will be affected by climate change, those who may hold misconceptions on climate change, those unmotivated to act or with contextual barriers that make it especially challenging for them, and audiences not used to immersive technologies such as the elderly. Second, studies may continue to be designed both as rigorous and controlled laboratory experiments but, to support ecological validity, studies in the real contexts of use and action should also be conducted. Multiple methods are potentially valuable, from the mix of qualitative and quantitative data to the study of longitudinal behavioral engagement and the triangulation of multiple collection methods, from video to psychophysiological measurements. Third, in terms of content and design, a wide variety of potentially productive message frames remain, as well as possibilities to embed games in day-to-day practices and the study of different game genres, exploration and game goal structures, social interaction, etc. Fourth, multiple variables relevant to climate change engagement remain underexplored through gamified methods, including some that have been probed here, such as self-efficacy, but also others like psychological distance, moderators such as worldviews, and mediators such as presence. Other aspects of the experience may continue to be studied in their complexity, such as the interactions between enjoying a serious game while being reminded of concerning aspects of reality, the tensions between a dire reality and hope, and the knowledge of issues alongside engagement in action. Beyond climate change engagement, related aspects such as nature connectedness are also aligned with the necessary change in values and practices for a sustainable future and are worthy of exploration through gamified methods, as are other grand challenges resembling and interrelated with climate change.

To conclude, this dissertation has aimed to adopt a critical perspective on gamified climate change and sustainability engagement. It has been proposed that play and games are important for sustainability for several reasons. One, they can be one source of non-destructive and meaningful joy as part of a sustainable present and future for humankind (Schmelzer et al., 2022). Two, they are one of the arenas in which sustainable values and attitudes can be promoted and exercised (Bookchin, 2006). And three, the above two are especially relevant given games' popularity (Wijman, 2020) and suitability to support education and motivation (Krath, 2021).

However, and despite these arguments, we should avoid turning the medium into a buzzword suggesting nebulous positive qualities, much like sustainability often is (Morelli, 2013). To avoid a fatal combination of unwarranted enthusiasm about unexamined gamification promoting superficial sustainability, I have aimed to support a (critical) realist view. Only in this way can research do justice to the complexities of both climate change engagement (Whitmarsh et al., 2015) and games as human activities and technologies, especially as we remain unable to quantify the true scale of global gaming's effects on players' climate change engagement and pro-environmental practices (Abraham, 2022). Even further, we should remain conscious that content is only a component of games' contribution to and relationship with global climate change, and games are just one element in the ecosystem of change; the larger issue is what, how, and how much is extracted, produced, and consumed in the world.

With these precisions in mind, the findings in this dissertation support the idea that games and gamification often lead to multiple forms of climate change engagement and meaningful experiences. These conclusions mirror my own experience as a researcher, player, and developer embedded in communities of practice, which is beyond the scope of the work presented but remains an important motivating element—in other words, researching, playing, and making games has kept me engaged with climate change. In parallel, the work done reveals multiple avenues to probe aspects that remain underexplored; thus, and partially due to its complexity, gamified climate change engagement remains a worthwhile exploration as there is still much to discover and discuss.

Climate change progresses fast, as does our relationship to it. On this moving train, the critical realist perspective gives scholars the task of envisioning possible and desirable futures for humankind and the world we inhabit. If concrete utopias are to be proposed in the future and they have a place for games and gamification in them, or are anticipated through playful means, I expect multiple other avenues to continue to be built beyond what I can anticipate. Our common future may greatly benefit from them.

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PUBLICATION I

**Gamification for climate change engagement:
Review of corpus and future agenda**

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TOPICAL REVIEW

Gamification for climate change engagement: review of corpus and future agenda

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Abstract

Both bottom-up and top-down initiatives are essential for addressing climate change effectively. These include initiatives aiming to achieve widespread behavioral change towards reduction of greenhouse gas emissions as well as pursuing education regarding adaptation measures. While awareness of the issue of climate change is now pervasive, and actions are being taken at all levels of society, there is still much to do if international goals are to be met. Games and gamification offer one approach to foster both behavioral change and education. In this paper, we investigate the state-of-the-art of game-based climate change engagement through a systematic literature review of 64 research outputs comprising 56 different gamified approaches. Our analysis of the literature reveals a trend of promising findings in this nascent and growing area of research, suggesting the potential to impact multiple engagement dimensions simultaneously, as well as create an engaging gameful experience. Overall, the corpus appears to offer a fruitful balance in foci between climate science, mitigation, and adaptation, as well as a variety of formats in game-based approaches (i.e. digital, analog, and hybrid). However, shortcomings were also observed, such as geographic and demographic imbalances and the short duration of interventions. The reviewed studies yield a large number of results indicating climate change engagement through gamification, especially in the form of cognitive engagement, affect towards climate change-related topics, and in-game behavioral engagement with others. Nevertheless, heterogeneity in terms of contexts, designs, outcomes, and methods, as well as limited rigor in research designs and reporting, hinders drawing overall conclusions. Based on our review, we provide guidelines regarding contexts, interventions, results, and research quality and internal validity for advancing the space of game-based interventions for climate change engagement.

1. Introduction and background

Climate change is currently seen as the primary threat across the planet (Poushter and Huang 2019) for biodiversity and human societies. As scientists warn of the dire impacts from present global warming through, for example, rising temperatures, heavy precipitation events and droughts (IPCC 2018), hundreds of legislative bodies and governments have declared 'climate emergency' to signal extraordinary resource mobilization (Climate Emergency Declaration 2020). At the same time such top-down governmental initiatives are implemented, widespread bottom-up engagement with and response to climate change is essential if targets for emissions reduction and energy saving are to be met (Hart and Feldman 2016).

To date, much progress has been made in understanding how to engage citizens and strengthen their motivations to reach equitable solutions (van

Valkengoed and Steg 2019). While past science communication has viewed climate change as a problem to be addressed by providing more information to the public (Moser and Dilling 2011), this information deficit model ignores other psychological barriers that stand between knowledge and concern and action, such as values, ideology, skepticism or distrust toward experts (Gifford 2011, Whitmarsh 2011).

Instead, experts have proposed to replace public understanding of science, which often adopts this approach, with public engagement in science, which focuses on dialog and acknowledges laypeople's situated understandings and contexts (Wibeck 2014). For example, appealing to societal and economic co-benefits of mitigation can have benefits in motivating those who deny anthropogenic climate change (Bain *et al* 2012). However, climate change engagement is not limited to understanding scientific facts or even the relevance of climate action. A person who is truly engaged with climate change is defined as manifesting three forms of connection: cognitive (knowing), affective (caring), and behavioral (acting) (Lorenzoni *et al* 2007), all of which can be connected to both mitigation and adaptation of climate change (Whitmarsh *et al* 2011).

Strategic engagement proposals have ranged from employing digital technology to provide 3D visualizations and interactive environments (Wibeck 2014) to an explicit mention of experiential learning environments (Sterman 2011). Experiential, inquiry-based, and constructivist interventions have been used in climate change education before (Monroe *et al* 2017). One opportunity is provided by gamification, understood as the use of games across society, culture and technology for purposes other than mere entertainment (Hamari 2019). Gameful designs continue to permeate our daily lives by supporting involvement in utilitarian contexts (e.g. education, health) through engagement and enjoyment (Koivisto and Hamari 2019).

This is not an entirely new concept: instrumental games exist since at least the middle ages (Von Hilgers 2012), while the tradition of digital serious games originates in the 1950s with the first digital computers (Djaouti *et al* 2011). However, games' increasing pervasiveness has led to several areas becoming gamified (Koivisto and Hamari 2019), especially where humans struggle with motivation and persistence such as education (Majuri *et al* 2018), health (Johnson *et al* 2016), and energy conservation (Johnson *et al* 2017). In the context of climate change, games and simulations have been used for almost forty years now (Robinson and Ausubel 1983). Diverse game reviews from the last decade show that the tendency has only grown since then (for example, see Reckien and Eisenack 2013) and evince that games address a wide range of learning goals, from knowledge increase to affective and behavioral engagement (Flood *et al* 2018, Rajanen and Rajanen 2019).

Four mechanisms in particular that have been proposed in prior literature (Den Haan and Van der Voort 2018, Dieleman and Huisingh 2006, Flood *et al* 2018, Plass *et al* 2015, Schroth *et al* 2014, van Pelt *et al* 2015) as driving the effectiveness of games in generating outcomes other than entertainment are an increased motivation through engaging experience, learning through active experimentation, social interaction, and visual representation. First, gamification supports motivation (Koivisto and Hamari 2019) by providing experiences of flow and immersion (Hamari *et al* 2016), i.e. completely capturing the player's attention. Games often provide feelings of competence, autonomy, and relatedness (Rigby and Ryan 2011), which not only drive player engagement but can empower them to act. Thus, an engaging game experience can enhance players' cognition, create positive emotions, and motivate behavior that enhances the public's response to climate change, either within or out of the game's frame. Second, and according to Piaget's theories and cognitive constructivism overall, learning occurs when the information received from experience is assimilated and accommodated (Powell and Kalina 2009). Indeed, games often provide interactive spaces where reality can be experienced and transformed. As proposed by Kolb (2014), this would be the basis for knowledge creation. Later conceptualizations of his experiential learning theory seem to highlight four elements: a concrete experience situated in a physical and temporal context, critical reflection, context-specific abstraction, and active experimentation (Morris 2020). Games can support learning by affording hands-on experiences in real or simulated contexts, providing different levels of abstraction and focus on specific features of reality, and including moments for individual or group reflection. In addition, challenges in games can adapt to the circumstances of specific players, providing customized guidance and feedback, and allow them to fail with low consequence (Plass *et al* 2015). Especially when combined with other methods and spread across multiple sessions, serious games have been found to be more effective than traditional instruction (Wouters *et al* 2013). Third, games often facilitate social engagement, for example, in multiplayer games or through fictional characters. According to social constructivist theories, ideas are built through social interaction (Powell and Kalina 2009), an effective strategy in terms of climate change education (Monroe *et al* 2017). Working in groups has been identified as a relevant aspect in serious games' effectiveness (Wouters *et al* 2013). Even single player game experiences can satisfy relatedness needs through interaction with non-player characters (Rigby and Ryan 2011). This allows games not only to provide information, but also a safe space to collectively interact with its causes and impacts, and to effect action. Fourth, another important element of games, visual representation, is believed to provide a series of learning aids and benefits to users, among which immersion, interaction, credibility, and self-assessment of climate change knowledge (O'Neill and Smith 2014), enhanced clarity, and understanding (Flood *et al* 2018). Furthermore, visuals improve the quality of deliberation and decision-making (Burch *et al* 2010).

Despite these promises, evidence on the effectiveness of game-based interventions to enhance climate change engagement is not well integrated. The literature, although offering many examples of specific game-based studies, does not offer an up-to-date synthesis of findings or a substantiated conclusion to guide research or practice. In particular, there is a lack of clarity on the contexts and target groups for which game-based solutions effectively enhance climate-related engagement, which design choices provide positive outcomes, to what extent individuals' engagement is actually improved, and how this improvement can best be measured and understood. These shortcomings in the literature are important because without a structured, evidence-based overview, game-based research for climate change engagement will remain in the domain of trial-and-error. In this context, an up-to-date systematic review of game-based climate change engagement research is needed to provide a broad picture of what scientists are attempting and reporting in this field, how, where and to whom, but also an explicit, informed direction regarding agenda-setting for the future.

This study is preceded by other reviews that examined similar research spaces. Some review articles have focused on a broader picture, for example by exploring social learning outcomes in game-based interventions about sustainability issues (Den Haan and Van der Voort 2018) or the use of simulations and serious games in sustainability education (Hallinger *et al* 2020). Others have investigated climate change itself but focusing on a narrower space. Flood *et al* (2018) reviewed 43 research outputs reporting game-based interventions for adaptation and concluded that achieving social learning outcomes was aided by factors such as trust between the actors involved, debriefing and evaluation, and the experience and knowledge of facilitators. Rajanen and Rajanen (2019) addressed climate change communication for public engagement using games and gamification but yielded a smaller sample. The 14 papers examined in their review reported overall positive results in terms of game effectiveness, but indicated a lack of quantitative, controlled experiments, and longitudinal studies that would provide more solid evidence.

This review aims at extending these reflections by examining the extant empirical literature on game-based climate change engagement. We aim to analyze the described interventions in four areas, each one connected to a research question exposed in section 2:

(a) Contexts and populations, including location, age, occupation, and previous relationship to climate change and related topics.
(b) Intervention design, including player roles, delivery method, format and length, application domain and topics, and game elements that 'structure games and aid in inducing gameful experiences within the systems' (Koivisto and Hamari 2019, p 193).
(c) Engagement results, including 1. cognitive, affective and behavioral engagement with climate change, and 2. psychological experience with the games themselves, contextualized through data collection and analysis methods.
(d) Quality appraisal and internal validity, hereafter referred to as 'strength.'

The results serve as the basis for a research agenda that offers scholars in this space current gaps and questions that will lead to new research avenues. The paper is structured as follows. Section 2 describes the systematic literature review process followed, including study planning, literature selection and data extraction. Section 3 reports the results from the 64 research outputs that were finally selected, including bibliographic data and variables organized in the four aforementioned areas. Section 4 presents the research agenda building upon the findings. Section 5 concludes the paper.

2. Methods

This study uses the systematic literature review approach. Systematic literature reviews 'adhere closely to a set of scientific methods that explicitly aim to limit systematic error (bias), mainly by attempting to identify, appraise and synthesize all relevant studies (of whatever design) in order to answer a particular question (or set of questions)' (Petticrew and Roberts 2008, p 9). Here, we aim to summarize the existing corpus of empirical research on game-based interventions for climate change engagement. By summarizing evidence, we intend to provide an understanding of the state-of-the-art in this area and direct future research by highlighting research and design gaps and opportunities (Paré *et al* 2015).

Furthermore, we aim to qualitatively appraise the studies in order to understand their reported effects. However, although we separately consider designs less prone to biases (such as controlled studies) or otherwise reliable in attributing effects to the intervention (such as before–after studies), we do not limit our sample to those. In being more open, we take into consideration the critical realist approach, acknowledging the value of multiple analysis methods and the fact that interventions are decisively influenced by their context (Paré *et al* 2015). As described by Okoli (2015), the process follows a protocol and consists of four consecutive stages: planning, selection, extraction, and execution, the fourth leading to the completed review.

2.1. Planning

The first stage starts with identifying the purpose of the study. In this case, we seek to answer the following questions, from which we will derive a future research agenda:

(a) In what populations and contexts have game-based climate change engagement interventions been applied?
(b) What types of games and gamification do such interventions implement, and what game design elements do they have?
(c) What does the literature report about the effectiveness of these interventions regarding engagement with climate change and with the games themselves?
(d) What is the quality and strength of the results?

Next, a protocol determining the procedures to follow throughout the research process is created. This section takes most of its content from the protocol.

2.2. Selection

The second stage includes the search for literature and the application of a practical screen in order to determine what studies are considered for review and which ones are eliminated before further examination (Okoli 2015). The screening process in this review follows two categories of inclusion criteria, with no additional exclusion criteria applied (e.g. time period):

Content applicability criteria:

(a) The source includes a description of a game-based intervention intended to engage a population with climate change through climate science knowledge, mitigation or adaptation practices, or reports outcomes regarding climate change engagement resulting from a game-based intervention.
(b) If the goal is to promote mitigation or adaptation practices, they must be explicitly connected to the larger context of anthropogenic climate change.
(c) The intervention reports empirically derived results.

Format criteria regarding the language and publication forum:

(a) The source is in English.
(b) The source has been published in a peer-reviewed journal, conference, or book.

The search process consists of automated database search combined with a forward snowball sampling of the studies that comply with the exposed criteria. The database search employed six relevant databases (Scopus, Web of Science, EBSCOhost GreenFILE, ProQuest Central, IEEE Xplore, and Google Scholar), yielding a total of 1453 results. See supplementary file S1 (available online at stacks.iop.org/ERL/16/063004/mmedia) for a detailed breakdown.

The basic search string used is the product of our knowledge from past research on this field, which includes both climate change and game-based interventions, an iterative search refinement process through diverse pilot searches, and familiarization with the unique requirements and limitations of each database. Due to technical limitations, the string was in some cases divided or otherwise adapted to produce the desired results:

(‘climate change’ OR ‘global warming’ OR pro-environmental OR (environment* OR ecolog* AND sustainab*) OR greenhouse OR low-carbon OR ‘energy efficien*’ OR ‘energy consum*’ OR ‘circular economy’ OR ‘recycl*’ OR ‘extreme weather’ OR ‘extreme event’ OR ‘environmental acti*’) AND (gamif* OR ‘game-based’ OR ‘board game’ OR ‘card game’ OR ‘video game’ OR videogame OR ‘digital game’ OR ‘mobile game’ OR ‘online game’ OR ‘computer game’ OR ‘serious game’ OR ‘educational game’ OR ‘role-playing game’) AND NOT ‘game theor*’ AND NOT computing.

Our inclusive approach aimed at narrowing down the results through the practical screen step. However, the refinement process led us to exclude from the search string terms such as ‘climate emergency’ or ‘climate crisis’ which did not yield any significant result not covered by other words, and ‘gaming,’ which introduced hundreds of irrelevant results. Given the amount of noise related to mathematical game theory and purely technical efficiency interventions (for example, algorithms for reduced screen energy consumption), we explicitly excluded two terms (‘game theor*’ and ‘computing’) from the search results.

The database search was conducted on 12 February 2020. After aggregating the search results and removing duplicates, two researchers conducted the screening process in two stages:

(a) The title and abstract of the retrieved studies were reviewed to reject the irrelevant papers. If needed, the reviewers skimmed over the full text.
(b) The retained papers were read in full and reviewed against the inclusion/exclusion criteria.

The two researchers screened the papers independently and met to compare the results in each of the two stages. Any disagreements in the process were discussed until a consensus was reached, and various iterations were completed to ensure that the entire sample was examined following the same criteria. Disagreements were fundamentally connected to two aspects: the boundaries of what a game-based intervention is, and what constitutes an empirical intervention. Disagreements were solved by being inclusive in our definitions: game-based interventions include playful events such as role-plays, game jams, and gamified participatory processes, while it was established that any study that includes data from participants, regardless of the level of detail reported, would be included, since this review includes a quality analysis not as a screening mechanism but as a method to answer its fourth research question. The outcome of the process was the list of primary studies to be reviewed systematically. The narrowing down process is shown in supplementary file S1. Once we identified the initial set of 51 primary studies, we conducted a forward snowballing process between 25 March and 6 May 2020 to detect further relevant studies citing them. This resulted in 547 articles to screen as described above. The full narrowing down process for the snowball sample, also presented in supplementary file S1, yielded 13 additional primary studies. Thus, in total we retained for systematic review 64 research outputs (supplementary file S2).

2.3. Extraction

The data extraction process aims at identifying features of interest in the papers reviewed in order to answer the research questions. While the units of analysis were determined beforehand, some specific values were discovered during the data extraction. The process was performed by the same two researchers in charge of the screening process, first independently and then aggregating the findings. The disagreements in coding were discussed until a consensus was reached. The variables were classified in five categories (one for bibliographic classification and four for answering the research questions including the quality assessment). Supplementary file S3 includes the database that serves as the basis for the results.

In summary, we complement previous reviews (Flood *et al* 2018, Rajanen and Rajanen 2019) with the following contributions to the process: comprehensive search phrase, broad database covering, and extensive snowball article sampling. Our research aims also differ from the previous reviews as we systematically examine not only outcomes, but also participants, contexts, and design features of the interventions, whether they address mitigation, adaptation, climate science, or other related topics. In addition, we exclusively consider studies that frame interventions within the phenomenon of anthropogenic climate change, regardless of the proximity of the mitigation or adaptation issues that players encounter in the games (e.g. saving energy or adapting to local floods). Although engagement strategies can address one or more dimensions (Whitmarsh *et al* 2011), policies risk failure and rejection when the public lacks understanding about climate change (Lorenzoni *et al* 2007). Given the fact that climate change requires not only bottom-up behavior change but also the acceptance of top-down initiatives, we focus on game-based approaches that can contribute to climate change understanding by relating personal issues to their broader context.

3. Results

In this section, we report the results from the data analysis of the 64 empirical research outputs. The results begin with identification and bibliographic data, followed by four sections that address the research questions: population and context (RQ1); intervention and game elements (RQ2); engagement results (RQ3); and quality and strength (RQ4).

3.1. Identification and bibliographic data

By year of first appearance online, the first papers in the area delimited by our search process were published in 2011. The number remained relatively stable with two to four papers per year until 2014. Since then, we observe an upwards trend with a peak in 2019, with 16 articles published (figure 1). The year 2020, with two publications at the moment of data collection, is incomplete.

Most papers, 76.6%, were published in academic journals, followed by conference proceedings (20.3%) and book chapters (3.1%). We identified 51 individual venues of which five have published more than one paper: Simulation & Gaming (7), Sustainability (4), Environmental Science & Policy (3), the International Journal of Environmental and Science Education (2), and the Journal of Science Communication (2).

To map the research outputs by scientific field, we used the subject-area tags associated with their publication venues in Scopus, where the same venue (including journals, conferences, and books) can be assigned to more than one field. However, only 75% of the papers were indexed by Scopus; thus, this analysis does not fully cover the sample. The most frequent fields were Environmental Science (24 papers) and Social Science (23), followed by Computer Science (13 papers), Business, Management and Accounting (11 papers), Engineering (9), Energy (6) Mathematics (4), and Earth and Planetary Sciences (2). Other tags had only one paper associated.

3.2. Population and context

Our first research question aims to characterize the populations that game-based interventions for climate change engagement target, as well as their contexts. We examine geographical location, age, occupation, and previous relationship to climate change and related topics.

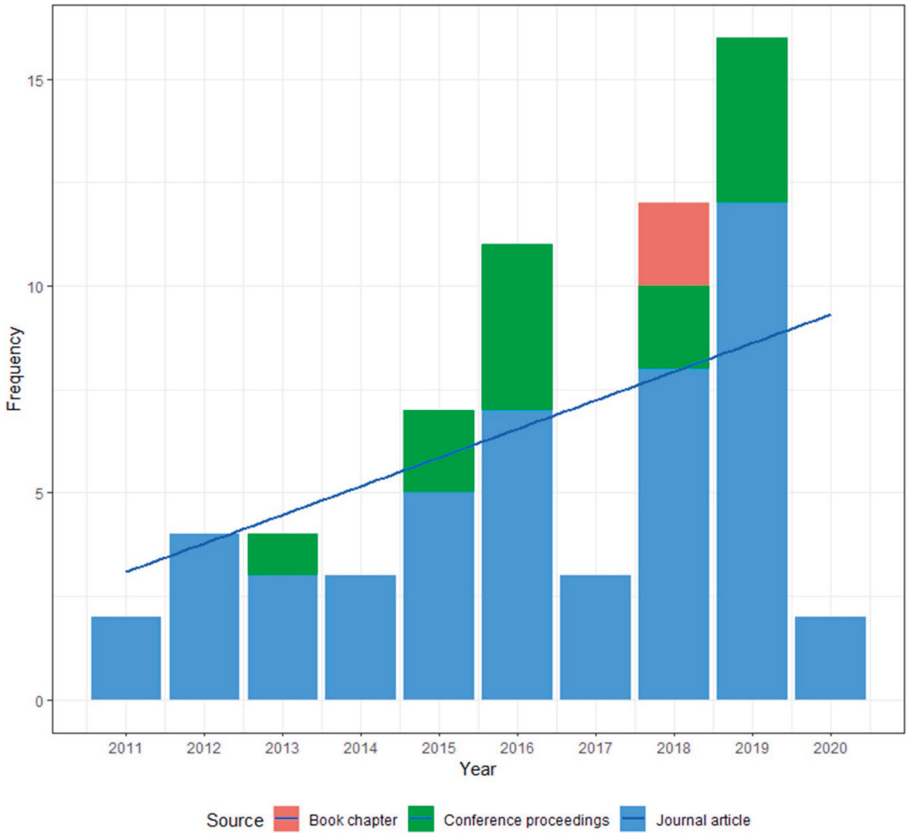

Figure 1. Number of publications per year.

3.2.1. Location

The main countries when considering first authors' affiliation are the Netherlands (with 18.8% of the papers, two thirds of which include adaptation in rivers as an important topic) and the US (17.2%). Nine other countries have more than one paper associated: Germany and the UK (7.8%); Norway and France (6.2%); Spain (4.7%); and Sweden, Canada, Austria, and Brazil (3.1%). When classified by country of intervention, papers exhibit a similar pattern to that of first authors' affiliations, with the US (17.2%) and the Netherlands (10.9%) being the most recurrent (figure 2). In cases in which the country was not reported but the intervention was in a physical space and all authors were from the same country, that was assumed to be the place of the intervention. Some papers (4.7%) described interventions distributed online, so the country was unknown and possibly multiple.

While 70.3% of the papers placed their interventions in advanced economies, only 26.6% included emerging and developing economies, according to the classification by the International Monetary Fund (2020). Three emerging countries had more than one research output: Kenya (7.8%), Brazil (4.7%), and Poland (3.1%). By continents, 50% of the research outputs included countries in Europe, 29.7% America, 12.5% Africa, 9.4% Asia, and 3.1% Australia or New Zealand.

3.2.2. Age and gender

In terms of age, 60.9% of the studies had adults as the only participant population. Participants under 18 years were the sole target in 23.4% of the studies, while 6.2% included both adults and minors. Another 9.4% did not report the participants' age groups. In contrast, 73.4% did not report the participants' sex or gender. Of those that reported this data, 47.1% presented samples with male preponderance (over 60%), 35.3% had between 40% and 60% of males, and 17.6% had more than 60% of females.

3.2.3. Occupation

By occupation, students, especially in tertiary education, were the most targeted population (table 1). Overall, 53.1% articles involved K-12 students (in

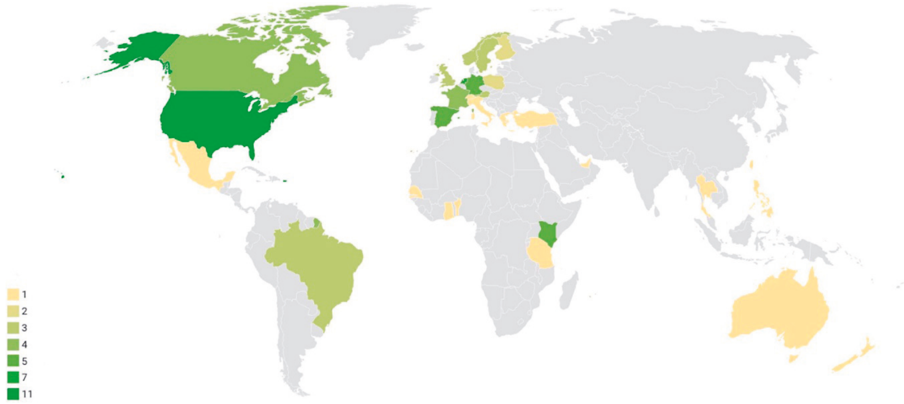

Figure 2. Number of papers by country of intervention.

Table 1. Number of papers by occupation.

Occupation	Frequency
Students (tertiary)	19
Students (K-12)	16
Farmers, fish farmers and farming stakeholders	12
Other professionals or unreported	11
Regional or national policymakers and decision-makers	8
Academics or educators	7
Local policymakers and decision-makers	6
Local citizens and other local stakeholders	5

primary or secondary education, usually between 5 and 18 years old), tertiary students, or both in one case, while 40.6% included professionals, academics, or stakeholders related to the topic of the intervention. Meanwhile, 17.2% included subjects whose occupation was unknown, unreported or not connected to the intervention topic or unique to one study (e.g. game developers or university staff). The total number surpasses 64 because papers often had more than one type of audience.

3.2.4. Previous relationship to climate change and related topics

Of the 64 research outputs, 40.6% did not report any previous contact or interest of the participants with climate change or related topics. In contrast, another 40.6% included participants who had a direct professional or (assumedly voluntary) educational involvement with the topic. Furthermore, 15.6% captured the participants' engagement with climate change prior to the intervention, where most participants reported a positive degree of involvement in at least one of the measured dimensions (beliefs, concern, knowledge). A generalized lack of awareness or interest in the topic of the intervention was reported in 3.1% of the papers.

3.3. Intervention content and design

To answer our second research question, related to types of gamification and their design elements, we analyzed how interventions characterize players; their delivery method; the game format, based on how technology is used; the duration of the intervention; the spatial scope of the intervention; the game topic, and the game elements. It is worth noting that, while the reviewed papers mentioned 56 unique games and gamified strategies, eight games appeared in more than one paper: WeShareIt (5), Keep Cool (3, including a digital version), Sustainable Delta (3), Forage Rummy (3), Catan (with the Oil Springs and Global Warming expansions) (2), two Future Delta iterations (2), Grazing Game (2), and The Maladaptation Game (2). Overall, we found very few of the reviewed game-based implementations to be accessible online in a digital format at the time of analysis. Of those available, some were commercial releases (Waddington and Fennewald 2018, Fjællingsdal and Klöckner 2019).

3.3.1. Player characterization or role

According to Wibeck (2014), engagement initiatives can conceptualize the public in different ways, such as economic actors who could engage in sustainable consumption, potential supporters of climate policy within a representative democracy, or participants in deliberative democratic action through dialog. Based on our analysis, 28.1% of the papers characterized players as consumers, promoting lifestyle changes as a way to act upon the climate crisis, while policy support was only found, rather tangentially, in one article (Hansen *et al* 2018). We found that 43.8% promoted participation in climate science and policy dialog, but they did so by simulating decision-making processes or affording peer discussion rather than providing a space for binding deliberation. Only one article (Steelman *et al* 2019) combined artistic exhibitions with communication exercises between policymakers and citizens. Beyond these categories, 32.8% engaged players in the context of a professional practice, such as farming, water management or policymaking; three interventions focused on climate science did not discuss an explicit response; and one paper educated on a purely technological solution, carbon capture and sequestration (Feldpausch-Parker *et al* 2013). While professional practice papers were naturally directed at adults, as were simulated participation papers (71.4% vs. 28.6% that included minors), consumer papers favored minors (55.6% vs. 38.9% that included adults).

3.3.2. Length, facilitation, and format

Most interventions (75%) occurred in a single session, while the rest extended the interaction to multiple moments of contact or allowed independent continued use for a period of time. Most papers, 54.7%, described facilitated interventions, so the players had the assistance of at least one expert that was present, available and participating in some capacity during the intervention. Meanwhile, 43.8% described independent interventions where players interacted with the game and each other largely autonomously. One additional study used both methods (Illingworth and Wake 2019). Most interventions that included simulated participation (63%) were facilitated, as were almost all that promoted professional practice (85.7%). Conversely, 77.8% of interventions that promoted a lifestyle change were meant to be used autonomously.

Game experiences adopted three main formats: digital, analog, and hybrid. The latter combined analog and digital approaches, e.g. role-plays supported with modelling software. In total, 26 digital games, 21 hybrids and 19 analog tabletop or role-playing games were described, including two that could be played both as a digital and board game (Erb 2015, Ouariachi *et al* 2019), totaling to 66 games. Two articles reported using two very similar games each (Rumore *et al* 2016, Gugerell *et al* 2018), which are combined for the purposes of this review.

Table 2 shows how different game formats were delivered; one analog game was offered with and without a facilitator in the same study (Illingworth and Wake 2019). Thus, the total number of individual game deliveries in the table is 67.

Table 2. Game formats and delivery methods.

	Digital	Hybrid	Analog	Total
Facilitated	3	20	13	36
Independent	23	1	7	31
Total	26	21	20	67

3.3.3. Application domain

The research outputs were classified in three application domains: those describing interventions focused on increasing knowledge about climate change from a climate science perspective (45.3%), on mitigation practices (59.4%), and on adaptation (53.1%). Most articles featured a single application domain, but combinations were also common (figure 3). Most papers with tertiary students focused on mitigation (84.2%), while those addressing climate science (52.6%) and/or adaptation (47.4%) were less frequent. Most interventions directed at K-12 students aimed at increasing climate science knowledge (87.5%) and mitigation behavior (75%), as did the ones with unreported or general public (63.6% and 100%, respectively). Papers including local citizens and stakeholders, policymakers, academics, or farmers almost always considered adaptation. In terms of player roles, mitigation was observed in all but one of the papers that framed the player as a consumer and promoted a lifestyle change, and in 88.9% of the papers that defined the player as participant in science or policy discussion. In contrast, adaptation was addressed in 95.2% of the articles that framed the player as a professional practitioner.

Regarding spatial scope, the most frequent framing of the topics represented was global. Yet, diversity is large (table 3). Articles with a multiple scope often related high-level general climate concepts to specific local and individual situations.

3.3.4. Game topics

Topics were directly coded from the reviewed literature, where often more than one topic is presented at once. Usually, climate science knowledge was related to its basic concepts related to climate change, for example the carbon cycle, as well as other scientific aspects of climate change (e.g. impacts on biodiversity). In the 34 adaptation papers, droughts and floods were the most common impacts (see table 4). Of the 38 mitigation papers, 76.3% considered it from an economic point of view (that is, as an issue involving production and consumption of energy and other goods and resources) and 47.4% involved policymaking, regulation and political negotiation, which can also affect the economic side.

3.3.5. Game elements

Games contain identifiable elements that generate the play experience (Koivisto and Hamari 2019). In this study, we have based our classification on that of Koivisto and Hamari (2019), but have included additional elements detected through the data extraction process and reorganized or deleted others previously

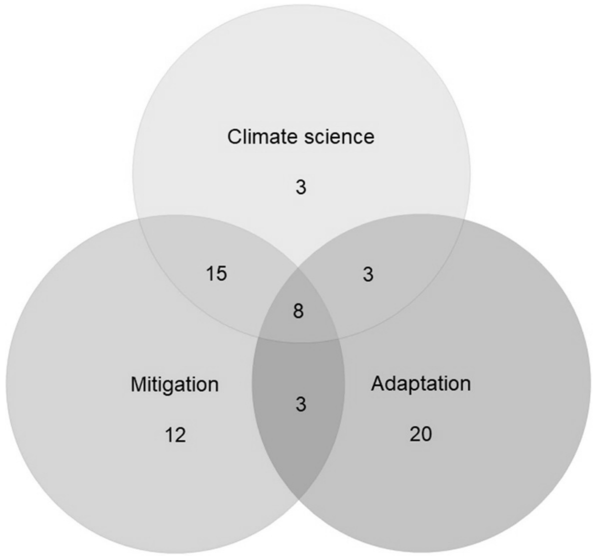

Figure 3. Number of articles by domain represented.

Table 3. Spatial scope.

Spatial scope	Climate science	Mitigation	Adaptation	Total
Global	11	13	3	27
Multiple	12	5	0	17
Water environments (coasts, rivers, lakes)	3	0	12	15
Farms and fish farms	0	2	11	13
Households or individual actions	0	9	1	10
Human settlements (cities, towns)	1	5	4	10
Countries and regions	1	2	2	5
Other professional environments	1	2	1	4
Total	29	38	34	101

Table 4. Climate science, mitigation, and adaptation topics by number of research outputs.

Topic	Climate science	Mitigation	Adaptation	Total
Economic mitigation	0	29	0	29
Generic awareness or climate science	24	0	0	24
Droughts	1	0	22	23
Policy-based mitigation	0	18	0	18
Floods	1	0	11	12
Unspecified or other climate impacts	5	0	6	11
High or rising temperatures	7	0	3	10
Sea level rise	6	0	4	10
Heavy precipitation	1	0	2	3
Pests and weeds	0	0	3	3
Storms	2	0	1	3
Threats to ecosystems	3	0	0	3
Desertification	0	0	2	2
Heatwaves	1	0	1	2
Prolonged growing season	0	0	2	2
Water quality	0	0	2	2
Weather variability	0	0	2	2
Ocean acidification	1	0	0	1

Table 5. Game elements' classification and frequency.

Game elements	Frequency
Achievement/progression-oriented	**273**
Challenges, quests, missions, tasks, clear goals	63
Levels (segmentation of gameplay into rounds, levels, missions...)	58
Performance and progress stats and feedback	56
Increasing difficulty	17
Points, score, experience	35
Quizzes, questions	15
Timer, speed	14
Leaderboards	9
Badges, achievements, medals, trophies	4
Player levels, unlockable skills and resources that the player keeps	2
Social-oriented	**97**
Cooperation, teams, collaboration	44
Competition, possible tension between diverging or conflicting interests	33
Customization, personalization	10
Peer-rating, also betting to review work of others	4
Social networking features (contact with non-players)	3
Collective voting	3
Immersion-oriented	**114**
Game world (visual representation)	48
Role play (interaction characterized as a fictional character, especially with other players)	24
Narrative, narration, storytelling, dialog with fictional characters	20
Avatar, player character, virtual identity	19
In-game rewards (obtained for performance, aside from points and badges)	3
Representation, resources, materials	**180**
In-game economy (a market where the player can at least buy goods)	28
Debriefing by facilitators	25
Physical playboard	25
Physical objects as game resources	19
Physical random number generation (dice)	11
Facilitators (with no debriefing)	11
Physical cards as resources	11
Physical cards as actions	8
Physical cards as events and challenges	8
Unexpected events with odds unbeknownst to players	9
Digital objects as game resources	6
Digital random number generation	5
Real-time dependence	5
Digital cards as actions	3
Digital cards as events and challenges	3
Connection to IoT devices	1
Real world interactive objects (for use with digital platform through direct interaction)	1
Physical cards as identity	1

classified as 'miscellaneous' in order to leave only four meaningful categories: elements that allow or quantify player achievement and progression through the system; elements that support social relationships; elements that uphold a sense of immersion in the game; and materials or resources (digital, physical or human) that represent other game concepts. In some cases, additional materials available online, such as design documents, appendices, or videos created by the game developers, have been used to clarify the meaning of certain elements. For this analysis, we consider Erb's (2015) two conditions as two separate games due to reported design differences, while Ouariachi *et al*'s (2019) game is understood as a single tabletop game due to lack of explanation in the original source. Another article that uses two tabletop games (Gugerell *et al* 2018) has also been considered as one item due to lack of detailed differentiation. Thus, the total number of games for design element analysis is 65.

All games described in the sample included at least one achievement-oriented element. This category was followed by immersion (81.8%), representation resources and materials (81.8%), and social (76.9%). Table 5 details the individual game elements within these categories and their number of occurrences in the reviewed literature. The reviewed

Table 6. Presence of element types by game format.

	Achievement	Social	Immersion	Representation, resources, materials	Total
Digital	25	11	20	14	25
Hybrid	21	21	17	21	21
Analog	19	18	17	19	19
Total	65	50	54	54	65

Table 7. Number of papers reporting engagement results (including all directions: positive, mixed and negative) by dimension and specific outcome.

Engagement dimension	Number of papers	Specific outcome	Frequency
Cognitive	50	Climate science knowledge	26
		Mitigation knowledge	21
		Adaptation knowledge	20
Affective	24	Individual affect (e.g. interest, responsibility, motivation, confidence, empowerment, importance of personal behavior change)	19
		Concern about climate change and its risks	6
		Collective affect (e.g. importance of cooperation, trust)	6
		Empathy for or understanding of others	3
Behavioral	35	In-game dialog, cooperation, and competition	21
		Personal mitigation behavior	8
		Produced outputs (e.g. games, adaptation plans)	8
		Personal involvement with study and information	3
		Community real-world decision-making	2
Game experience	41	Preference and other benefits	21
		Enjoyment, fun, motivation	18
		Game experience issues	13
		Intense participation	7

game-based designs almost ubiquitously relied on three achievement elements: challenges and clear goals, levels, and performance and progress statistics and feedback. Those that included social features exhibited cooperation-oriented elements more commonly than competition, but they are often combined. Immersion-wise, many chose to represent in-game worlds, either fictional or based on real spaces, visually.

When classified by format (table 6), digital experiences tend to lack social elements (in this sample, mainly cooperation and competition), while hybrid and analog games are usually designed as social activities. Representation, resource and material elements, which usually refer to facilitators and physical objects but include digital representations of physical objects as well, are also higher in hybrid and analog games.

3.4. Engagement results

Our third question relates to intervention effectiveness. Our definition of effectiveness broadly encompasses any reported results evincing engagement with climate change or the games themselves. After extracting evidence of climate change engagement, or reported lack thereof, we classified each result in the three categories described by Lorenzoni *et al* (2007): cognitive, affective and behavioral. In addition, we collected evidence related to engagement with games themselves, also called 'psychological outcomes' in gamification literature (Koivisto and Hamari 2019). Other findings presented in the papers, for example those related to games uncovering what participants already do in their lives, were not considered in this review. Consequently, we only report data collection and analysis methods used to uncover engagement. We also classify papers according to the direction of their results, either positive (engagement was reported), mixed (engagement results were reported but they were weaker than hypothesized, conditional, or limited by negative effects), or negative (indicators of disengagement were reported), taking separate note of results from statistical tests.

As depicted in table 7, the most reported form of engagement is cognitive, followed by experiences with the games. In some cases, a paper reported multiple specific outcomes within the same dimension (e.g. knowledge about climate science and mitigation topics). While cognitive engagement results are balanced in terms of the three application domains, most affective results represented generally positive changes in players' emotional relationship towards climate change and their own actions (increased interest, increased appreciation of the environment, reduced fatalism, a sense of empowerment, responsibility, motivation to act in the future, or perceived importance of their own behavior change). As shown in table 7, the most reported behavioral engagement results consist of dialog between players and actions

Table 8. Direction of results by engagement dimension.

Engagement dimension	Number of papers	Qualitative or descriptive results			Statistical results		
		Positive	Mixed	Negative	Positive	Mixed	Non-significant
Cognitive	50	37	3	0	11	0	2
Affective	24	14	2	1	6	1	1
Behavioral	35	29	3	0	3	1	0
Game experience	41	27	9	3	1	1	0

Note. The number of papers is higher in the results section than in the overall count because five papers reported more than one type of result in the same engagement dimension. One paper reported both statistically positive and mixed cognitive results; two reported statistically non-significant and positive cognitive results; one reported statistically non-significant and positive affective results; and one reported statistically positive and positive behavioral results.

Table 9. Results by data collection method.

Data collection method	Frequency	Engagement dimension			
		Cognitive	Affective	Behavioral	Game experience
Questionnaire	39	29	19	10	18
Observation, including recordings, notes, and non-systematic data-logging	23	12	2	14	9
Debriefing, focus group or panel discussion	17	13	2	4	6
Data log from gameplay and outputs	13	7	0	10	1
Interview	12	9	4	4	5
Unknown	4	2	1	1	3
Concept mapping	2	2	1	0	0
Essay or presentation	2	2	1	2	1

such as cooperation and competition within the context of the game.

In all four types of engagement measured, most results are positive or statistically positive (table 8). Game experience is the only dimension with a relatively large number of mixed results (24.4%). No article reported effect sizes for statistically non-significant results.

Although infrequent, non-positive results can be found across the three climate change engagement dimensions and especially in game experiences. The reported cognitive issues include, for example, mistrust and rejection of game models (e.g. Waddington and Fennewald 2018). Affective issues include induced fatalism due to extreme difficulty (Waddington and Fennewald 2018) and a decrease in trust in others as a result of game interaction (Onencan *et al* 2018), as well as failures to significantly increase self-efficacy or pro-environmental motivation (e.g. Ouariachi *et al* 2018). Regarding behavioral outcomes, some papers report e.g. limited behavior change (Waddington and Fennewald 2018), lack of interaction with science materials (Foltz *et al* 2019) or limited in-game cooperation (Onencan and Van de Walle 2017). Finally, game engagement issues often refer to perceived confusion or complexity (e.g. Illingworth and Wake 2019) and lack of freedom, enjoyment or challenge (e.g. Fjællingsdal and Klöckner 2019), to name the two most common.

It must be acknowledged here that no studies in the sample reported offering external incentives for real-world mitigation or adaptation behaviors. One paid study (Waddington and Fennewald 2018) offered an economic incentive to players that won the in-game scenario, which could have encouraged a participant to reportedly hack the game in order to be able to understand its system better and complete the task, but this reward was exclusively tied to the (digital, single-player) game. In another, students of a gamified course were rewarded with bonus points in their grades for studying in advance (Toriz 2019), which should be considered in relation to their reported increase in advance study and higher grades when compared to others receiving non-gamified teaching. Three studies only compensated participants for their participation with the chance to win prizes (Foltz *et al* 2019), a small allowance to cover travel costs and time (Lebel *et al* 2016), and free lunch (Schroth *et al* 2014).

3.4.1. Data collection methods

The data collection methods employed to detect climate change engagement outcomes were analyzed and coded (table 9). Most outcomes resulted from

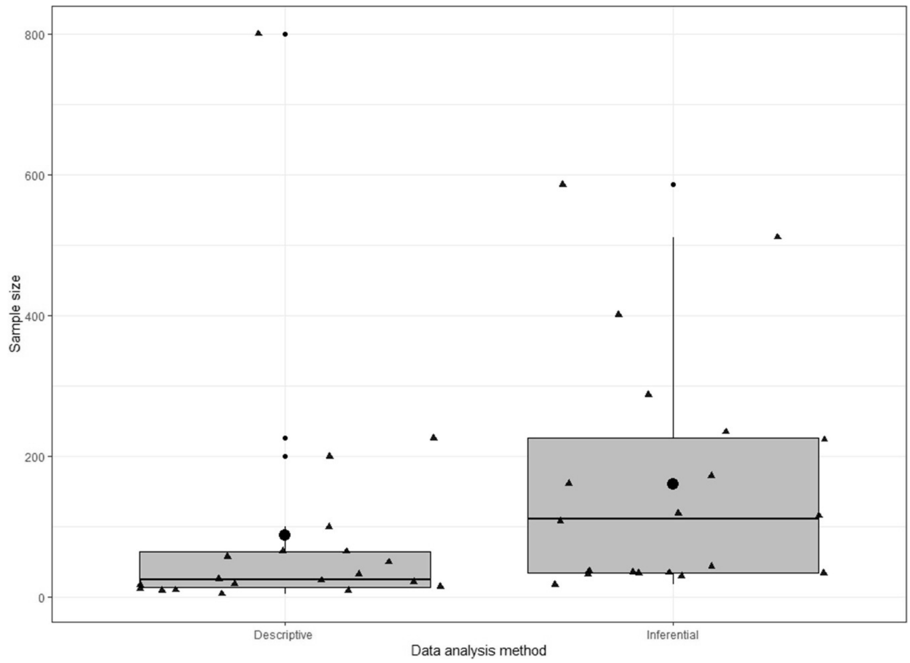

Figure 4. Sample sizes for descriptive and inferential studies.

the use of questionnaires across the categories except behavioral, which was frequently observed or logged. Of the 29 questionnaires used for cognitive outcomes, 41.4% included knowledge questions to assess the participants' learnings beyond self-reports or observations. One interview and one concept map provided similar data.

Figure 4 illustrates the sample size distributions of descriptive studies ($n = 20$, $M = 88.4$, SD $= 178.19$) and inferential studies ($n = 20$, $M = 161.25$, SD $= 168.48$) using boxplots. The sample size for each study is depicted with a triangle and the mean value per category is illustrated with a black dot. The depicted boxplots facilitate a preliminary comparison between the two distributions. More precisely, descriptive studies tend to use smaller samples, while inferential studies tend to have a higher variance but a higher mean value overall.

3.4.2. Data analysis methods

Of all the research outputs, 71.9% analyzed engagement data qualitatively, 31.2% analyzed quantitative data using inferential methods (i.e. statistical tests to examine hypotheses and make deductions), and 32.8% reported descriptive statistics of data. However, papers often mix methods: 37.5% were purely quantitative, 14.1% were purely descriptive, 10.9% were purely inferential, 17.2% mixed qualitative and descriptive methods, 17.2% mixed qualitative and inferential methods, and only two mixed descriptive and inferential methods. Most data analysis methods are used to report cognitive climate change engagement (table 10).

Of the 24 studies that reported data qualitatively, 23 were case studies; the remaining one was a quasi-experiment that reported engagement data only through debriefing and observation (Dah-gbeto and Villamor 2016). The nine descriptive studies presented four before–after designs and five case studies in which data was collected only during or after the intervention, one of which presented participants with screenshots of an app (Petersen *et al* 2019). The seven inferential papers include five before–after designs, one quasi-experiment that records data during gameplay, and one controlled experiment (Nussbaum *et al* 2015). Of the 11 papers that mix qualitative and descriptive methods, six were case studies that collected data only during and after the intervention, four were before–after designs and one included a control group for comparison (Toriz 2019). The 11 papers using qualitative and inferential methods include one study that measured engagement only after the intervention, six before–after designs and four controlled studies. Two papers present engagement results supported by quantitative data analyzed in descriptive and inferential ways: one is a before–after design (Feldpausch-Parker *et al* 2013) and the other collects gameplay data (Piccolo *et al* 2016). Overall, only 26 studies in the sample include either before–after measurements or a control group.

Table 10. Engagement results by data analysis methods, in number of papers.

Data analysis methods used	Number of papers	Engagement dimension			
		Cognitive	Affective	Behavioral	Game experience
Qualitative	**24**	**19**	**5**	**15**	**15**
Descriptive	**9**	**8**	**5**	**4**	**6**
Inferential	**7**	**5**	**2**	**2**	**1**
Qualitative and descriptive	**11**	**9**	**3**	**7**	**10**
Qualitative				1	4
Descriptive		5	2	2	3
Qualitative and descriptive		4	1	4	3
Qualitative, descriptive, and inferential	**11**	**7**	**9**	**6**	**7**
Qualitative			3	2	5
Qualitative and descriptive		1		2	2
Qualitative and inferential		2			
Inferential		3	5	2	
Inferential and descriptive		1	1		
Descriptive and inferential	**2**	**2**		**1**	**2**
Descriptive		1		1	1
Inferential		1			1

Note. Some papers with qualitative and inferential methods include descriptive data as support.

Furthermore, only five articles in the total sample measured some form of climate change engagement beyond immediately after the intervention.

3.4.3. Engagement findings in high and medium strength papers

In this sample, 40.6% of the papers have been classified as of high or medium strength due to their designs, which provide stronger evidence of game effects on climate change engagement (see section 3.5). Twenty compare before and after measurements, while six include control groups. Of the six papers with control conditions, two compared games with other media containing equivalent climate change information (Smith *et al* 2019, Toriz 2019). The rest involved 'not playing' (Ouariachi *et al* 2018), a non-climate change related science website (Nussbaum *et al* 2015), the same game with different settings (Van Pelt *et al* 2015), and a non-climate change game (Waddington and Fennewald 2018). Another study that tested the same game in board and digital format using diverse player groups (Erb 2015) was considered a qualitative paper due to it having different before and after measurements, which were presented qualitatively, and allowing part of the players to experience both conditions, thus it is not included here.

In terms of data collection, these studies use 64.1% of the questionnaires in the sample but only 35.3% of debriefs, 33.3% of interviews, 30.8% of data logs, and 29.4% of interviews. Regarding data analysis, four report findings using descriptive methods, one uses descriptive and inferential, five qualitative and descriptive, six inferential, and ten qualitative and inferential. As can be seen in table 11, cognitive and affective outcomes are often measured statistically, while reports on behavioral and game engagement are often either qualitative or descriptive.

Here, we examine their outcomes in more detail, including possible connections between results and specific game elements. One ideal approach to understand the effects of isolated game features would be the value-added game research paradigm, since it compares two player groups, one with a base game and another playing the same game with one specific element added (Mayer 2019). Regrettably, none of the papers adopted such an approach. However, we can still establish qualitative connections between reported game elements and results, indicating how different features can enable the changes observed, although it must be acknowledged that no comparison of the same intervention without those elements exists. In addition, supplementary file S4 shows the relationships between engagement results and game elements.

3.4.3.1. Cognitive engagement

Of the 20 research outputs that reported cognitive engagement-related results, 12 employed questionnaires or concept map assignments that tested participants' knowledge. This represents 85.7% of all test-like methods used in the sample. Through this assessment method, games have been found to increase cognitive engagement with climate science, mitigation, and adaptation. Climate science topics include, for example, climate literacy (e.g. Harker-Schuch *et al* 2020), knowledge regarding global change (Pérez-Fernández *et al* 2019), climate change causes, impacts and solutions (Angel *et al* 2015), and overall understanding of climate change as a systemic phenomenon (Waddington and Fennewald 2018). In some cases, however, studies failed to report statistically significant results (e.g. Van Pelt *et al* 2015) or authors noted that learning outcomes depended on the players' acceptance level of the game modeling of climate change (Waddington and Fennewald 2018). Cognitive engagement about mitigation included

Table 11. Results from high and medium strength papers.

Engagement dimension	Number of papers	Qualitative or descriptive results			Statistical results		
		Positive	Mixed	Negative	Positive	Mixed	Non-significant
Cognitive	20	11	1	0	9	0	2
Affective	16	7	1	1	6	1	1
Behavior	12	8	1	0	3	1	0
Game experience	16	10	4	1	1	0	0

topics such as energy use (Toriz 2019) and carbon capture and sequestration (Feldpausch-Parker *et al* 2013). Participants were also engaged with adaptation through water conservation (Nussbaum *et al* 2015), and water management in situations of flood and drought risk (Bathke *et al* 2019).

Other assessment methods have also been used to report engagement with all three aspects: climate science, articulated in sustainability awareness (Chappin *et al* 2017), knowledge about climate risks (Rumore *et al* 2016), and climate consequences (Hoyos *et al* 2019); mitigation, including energy transition concepts (Ouariachi *et al* 2019), the impact of personal actions (Lee *et al* 2013), and the importance of sharing wealth between nations (Scarlatos *et al* 2013); and adaptation through topics such as cooperation (Onencan *et al* 2019) and situational awareness (Onencan and Van de Walle 2018).

As occurs with the overall sample reviewed, the vast majority of these interventions seemed to rely on game elements related to player achievement: a goal was the basic building block for players to engage with learning content. The majority used challenges with an explicit score, gameplay segmentation and performance feedback. Some studies added other achievement features to support cognitive engagement, such as quizzes (e.g. Harker-Schuch *et al* 2020), or complemented challenges with an increasing difficulty progression (e.g. Pérez-Fernández *et al* 2019) or timers (Bathke *et al* 2019).

However, the corpus indicates that certain cognitive outcomes may be connected with other specific game elements. In some cases, it seems crucial to immerse the action in a known environment (e.g. Nussbaum *et al* 2015). Other games brought abstract climate science to life through immersive elements such as avatars, stories and characters, and visual worlds (e.g. Harker-Schuch *et al* 2020). When preventing the tragedy of the commons, collaboration and competition in the face of random impacts were key (Chappin *et al* 2017); other games increased awareness of cooperation precisely through multiplayer mechanics (e.g. Onencan *et al* 2019). Achieving learning outcomes through simulated relevant mechanisms also occurred, for example, when teaching about the importance of sharing wealth by using an economy game element (Scarlatos *et al* 2013) or by introducing unexpected climate impacts (Onencan *et al* 2019). In class settings, competition for grades can be mirrored in gamified systems (Toriz 2019). Facilitation (Hoyos *et al* 2019) and especially debriefs (e.g. Rumore *et al* 2016) were cited as methods for reflection and sense-making. Few games employed customization (e.g. Yamada *et al* 2019), badges (Toriz 2019), or reward systems (e.g. Waddington and Fennewald 2018). Table 12 summarizes all of the cognitive engagement results, including details about the associated interventions, and the game elements reported in the high and medium strength interventions (for more details, see supplementary files S3 and S4).

3.4.3.2. Affective engagement

Sixteen papers reported affective engagement outcomes. As expected, achievement mechanics, at least missions and feedback, were used throughout the corpus. The importance of a well-balanced challenge is reinforced by the experiences in Waddington and Fennewald's (2018) study, where excessive difficulty led to fatalism. However, other elements besides the achievement group can be connected to affective engagement. For example, immersive games with avatar-supported role-plays (Rumore *et al* 2016) or avatars within a story-driven local, visual game world (e.g. Angel *et al* 2015) were found to increase concern. In addition, Schroth *et al*'s (2014) intervention increased perceived local responsibility and support for more radical policies. Challenges situated in visual local environments raise interest in water conservation (Nussbaum *et al* 2015). Including uncertain climate impacts favored responsibility towards the climate (Meya and Eisenack 2018) and was described as 'psychological(ly) strong' (Van Pelt *et al* 2015, p 46).

Social elements were one important category for affective results. Multiplayer role-plays seemed to enable empowerment (e.g. Rumore *et al* 2016) and other social experiences brought personal attitude changes towards sustainability or the environment (e.g. Chappin *et al* 2017). Social games resulted in motivation to teach and discuss with others (e.g. Lee *et al* 2013) or research topics discussed in the game (Hoyos *et al* 2019). However, issues with graphics and perceived lack of interactivity in a digital experience played in pairs brought non-significant increases in

Table 12. Presence of game elements and cognitive engagement results in high and medium strength papers.

Game elements	Cognitive engagement results
Achievements/progression Challenges (20); feedback (19); levels (18); points (14); quizzes (7); increasing difficulty (6); timers (5); leaderboards (4); badges (4). **Social** Cooperation or collaboration (13); competition (9); customization (3); peer-rating (2); collective voting (1). **Immersion** Visual game world (16); avatar (8); stories or characters (8); role-play (6); in-game rewards (2). **Representation, resources, materials** Debriefing (7); physical playboard (6); in-game economy (6); physical or digital objects as game resources (5); unexpected events (3); real-time dependence (2); randomness (1); facilitators (1).	**Engagement with climate science** • Retention of climate change causes and local impacts; increase in knowledge about the carbon cycle and other climate science topics; improvement in climate literacy through single-player digital games; increased understanding of coastal ecosystems and conceptual broadening of climate change; learning about climate change science concepts; and knowledge about basic concepts of climate change (single-player digital games, K-12 students) • Increase in understanding about global change (multiplayer board game, K-12 students) • Positive change in awareness and understanding of sustainability issues (observed, but the game's effects on knowledge are non-significant) (multiplayer board game, adults) • Increased knowledge of climate change causes, dynamics, and impacts (hybrid role-play, K-12 and tertiary students) • Increased understanding of climate change as a system (single-player digital strategy game, players' background unknown) • Better understanding of the environmental crisis and its consequences (multi-player hybrid simulation gamifying a course, tertiary students) • Increased awareness of climate change risks at the local level (role-play simulations, local stakeholders) **Engagement with mitigation topics** • Retention of possible local climate change solutions; knowledge about carbon capture and sequestration; and learning about personal actions for mitigation (digital single-player games, K-12 students) • Increased academic performance in a course about energy use (gamified flipped classroom, tertiary students) • In-game fight against the tragedy of the commons (multiplayer board game, adults) • Understanding how personal actions affect global warming (gamified digital app, tertiary students) • Increased awareness about local energy transition and the need for collaboration (analog and digital game played in groups, K-12 students) • Knowledge about country-level mitigation measures and awareness of the importance of sharing wealth internationally to combat climate change (multiplayer digital simulation, tertiary students) **Engagement with adaptation topics** • Knowledge on aspects of water quality and mitigating droughts and floods in the context of water management (hybrid multiplayer game, multiple stakeholders) • Water conservation knowledge, abandoned misconceptions related to weather and climate and the ozone layer (single-player digital game, K-12 students) • Learning about water cooperation and team interdependence; and significant increase in situational awareness (multiplayer hybrid game, decision-makers) • Increased perception that uncertainty complicates preparing for adaptation (role-play simulations, local stakeholders) **Issues** • Diversity in learning outcomes influenced by acceptance of a computer strategy game's simulation model (players' background unknown) • Broader understanding of climate change uncertainty, but learning effect inconclusive (non-significant) (hybrid simulation game, water managers)

self-efficacy and limited willingness to make behavioral changes (Ouariachi *et al* 2018).

Positive social attitudes were related to in-game social actions in some cases. Games where players interact with peers have resulted in increased optimism about international (Meya and Eisenack 2018) or local (Ouariachi *et al* 2019) cooperation, local and personal confidence regarding climate adaptation (Rumore *et al* 2016), increased perception of self-trustworthiness after playing (Onencan *et al* 2018), and perceived importance of cooperation and empathy for other game participants and their viewpoints, and appreciation of different perspectives enacted through role-taking (Rumore *et al* 2016). However, competitive dynamics might have also decreased trust after participating in a multiplayer exercise (Onencan *et al* 2018). Table 13 summarizes all of the affective engagement results, including details about the associated interventions, and the game elements reported in the high and medium strength interventions (for more details, see supplementary files S3 and S4).

3.4.3.3. Behavioral engagement

Twelve papers reported some form of behavioral engagement, although this often occurred inside the game. In-game discussions could occur through virtual identities and inside a story (Lee *et al* 2013), but social experiences were also common. These resulted in social learning (e.g. Bathke *et al* 2019), in-game cooperation (e.g. Onencan *et al* 2019), the formation of new professional connections (e.g. Bathke *et al* 2019), and self-reported change of behavior (Chappin *et al* 2017). Translation of game action to community decision-making was observed after role-playing (Rumore *et al* 2016), a similar game was linked to students reducing their carbon footprint (Oliver 2016), and another tied behavior change directly to its mission goals (Lee *et al* 2013). Multiplayer gamification also increased course participation (e.g. Toriz 2019). Indirectly, unexpected climate impacts can be used as symbols to foster climate change familiarity (Onencan and Van de Walle 2018), critical for situation awareness. On a more negative note, fatalism derived from extreme difficulty could be related to lack of behavior change (Waddington and Fennewald 2018). Table 14 summarizes all of the behavioral engagement results, including details about the associated interventions, and the game elements reported in the high and medium strength interventions (for more details, see supplementary files S3 and S4).

3.4.3.4. Game experience

Finally, 16 papers in this subset reported outcomes related to being engaged with the game itself. Although most measured/reported outcomes were positive, including experiences of enjoyment, entertainment, fun, appreciation and general interest and engagement, some players criticized games as inadequate methods to address serious issues (Bathke *et al* 2019), seemed to refuse to engage with some tasks due to them providing little personal value (Piccolo *et al* 2016), reported confusion and excessive difficulty (e.g. Waddington and Fennewald 2018), or criticized games' mechanics, graphics (e.g. Ouariachi *et al* 2018) and technical issues (Yamada *et al* 2019), especially in digital experiences. In these cases, positive experiences seem derived from adequate implementations of game design elements rather than simply using them or not. Players can appreciate immersive games with avatars, stories and/or characters (e.g. Schroth *et al* 2014), social interaction (e.g. Pérez-Fernández *et al* 2019), and facilitation (e.g. Hoyos *et al* 2019). Meanwhile, role-playing games can be at the same time appreciated and criticized for being games (Bathke *et al* 2019). Games with achievement elements can also lead to engaging experiences, for example those with quizzes and badges (Toriz 2019). In some cases, players explicitly appreciate game challenges (Yamada *et al* 2019), but also consider them too difficult and opaque to be enjoyable (Waddington and Fennewald 2018). Table 15 summarizes all of the behavioral engagement results, including details about the associated interventions, and the game elements reported in the high and medium strength interventions (for more details, see supplementary files S3 and S4).

The results from the sample, and especially from medium and high strength studies, suggest an optimistic future for game-based climate change engagement, especially when studies aim to increase cognitive engagement, affective engagement including motivation to act and interest towards climate change, or in-game social interaction related to climate change. However, heterogeneity in terms of contexts, designs, outcomes and methods hinders drawing global conclusions.

3.5. Quality and strength

This section appraises the studies' quality and ranks their design strength as an indicator of internal validity. These data will help to assess the extent to which the outcomes and results reported above are reliable in their context. Given the broad perspective taken in this review, where multiple interventions for multiple populations are considered, we are not as concerned with the individual studies' external validity or generalizability; it is the overview that provides the wider angle.

3.5.1. Quality appraisal

We assessed the papers' quality through a checklist adapted to the purposes of this review from the examples provided by the Critical Appraisal Skills Programme (n.d.) (see table 16 for details). The score for each of the quality assessment questions (either 0, 0.5, or 1) was assigned independently and then discussed between the two researchers until an agreement was reached for each paper. Overall independent perceptions of quality were similar in all cases and discrepancies were typically at the level of half point.

We classified results in three groups according to our overall judgement after conducting the quality assessment: low quality, when out of 8 possible points the paper scored below 5 (17.2%); medium quality, when it scored between 5 and 6.5 (40.6%); and high quality, when the score was between 7 and 8 (42.2%). In practice, no paper obtained a score under 2. When mapping the quality of the articles versus the years of first publication, we observe a slightly upwards tendency and stabilization in 2017 with the average quality score around 6 (figure 5). The period 2018–2020 has seen more high-quality papers being published than in all the previous years combined, but the number of low-quality papers has also grown.

Table 13. Presence of game elements and affective engagement results in high and medium strength papers.

Game elements	Affective engagement results
Achievements/progression Challenges (16); feedback (14); levels (14); points (10); quizzes (4); increasing difficulty (4); timers (3); leaderboards (3); badges (2). **Social** Cooperation or collaboration (12); competition (8); peer-rating (2); customization (1); collective voting (1). **Immersion** Visual game world (12); stories or characters (6); role-play (6); avatar (5); in-game rewards (1). **Representation, resources, materials** In-game economy (6); debriefing (5); physical playboard (5); physical or digital objects as resources (5); unexpected events (2); randomness (2); real-time dependence (2); facilitators (1).	**Individual attitude improvements** • Increase in perceived responsibility (multiplayer board game, K-12 students) • Increased interest in water conservation (single-player digital game, K-12 students) • Increased appreciation of the environment (role-play, tertiary students) • Increased intent to engage in discussions and political action (hybrid role-play, K-12 and tertiary students) • Feeling of empowerment to use new information and skills (hybrid multiplayer game, multiple stakeholders) • Positive changes in people's attitude towards sustainability sustainable behaviors (multiplayer board game, adults) • Motivation to research discussed topics (multiplayer hybrid simulation gamifying a course, tertiary students) • Empowerment, reduced fatalism, motivation to teach others (gamified digital app, tertiary students) • Confidence about own and other organizations' capacity to adapt (role-play simulations, local stakeholders) • Activation to learn about climate uncertainty (hybrid simulation game, water managers) • Increased trustworthiness (multiplayer hybrid game, decision-makers) • Small rise in self-efficacy (digital and board game played in groups, K-12 students) **Concern about climate change and its risks** • Increased concern about climate change effects (digital single-player game, K-12 students) • Concern about local risks (role-play simulations, local stakeholders) • Concern about local impacts, support for more radical policies, sense of local responsibility (tertiary students, single-player digital game) • Greater urgency and hope (hybrid role-play, K-12 and tertiary students) **Positive observations on collective affect** • Optimism about international cooperation, less pessimism on political measures for mitigation (multiplayer board game, K-12 students) • Slight increase in collective self-efficacy about local energy transition (digital or board game played in groups, K-12 students) • Increased confidence about collective adaptation action and perceived importance of engaging many points of view in adaptation (role-play simulations, local stakeholders) **Empathy for or understanding of others** • Increased empathy and recognition of others' perspectives (role-play simulations, local stakeholders) **Issues** • Fatalism due to game difficulty (single-player computer strategy game, unknown age) • Decreased trust after engaging in multiplayer competitive dynamics (multiplayer hybrid game, decision-makers) • Non-significant increase in self-efficacy, limited willingness to save energy (associated with issues with graphics and perceived lack of interactivity in digital games, K-12 students)

Table 14. Presence of game elements and behavioral engagement results in high and medium strength papers.

Game elements	Behavioral engagement results
Achievements/progression Challenges (12); levels (11); feedback (10); points (8); leaderboards (5); increasing difficulty (5); timers (4); badges (3); quizzes (2). **Social** Cooperation or collaboration (11); competition (10); customization (2); peer-rating (2); collective voting (1). **Immersion** Visual game world (7); avatar (7); stories or characters (3); role-play (3); in-game rewards (1). **Immersion** Visual game world (7); avatar (7); stories or characters (3); role-play (3); in-game rewards (1). **Representation, resources, materials** Debriefing (6); in-game economy (6); physical playboard (4); physical or digital objects as game resources (4); unexpected events (3); facilitators (2); randomness (1); real-time dependence (1).	**In-game dialog, cooperation, and competition** • Dialog, new collaboration opportunities (multiplayer hybrid game, multiple stakeholders) • Discussion in in-game missions (gamified digital app, tertiary students) • Interdependence, social connections developed (multiplayer hybrid game, decision-makers) • Cooperation and competition in a realistic scenario (multiplayer hybrid game, decision-makers) • Coordination among groups in a social simulation (hybrid role-play, K-12 and tertiary students) **Personal mitigation behavior** • Behavior change on sustainability issues (multiplayer board game, adults) • Behavior change after playing (gamified digital app, tertiary students) • Decrease in carbon footprint after participating (role-play, tertiary students) **Produced outputs (e.g. games, adaptation plans)** • Generation of useful content through gameplay (gamified digital app, tertiary students) **Personal involvement with study and information** • Participation and involvement in a university course (multiplayer hybrid simulation gamifying a course, tertiary students) • More study (gamified flipped classroom, tertiary students) **Community-level real-world decision-making** • Integration of in-game projections into local decision-making (role-play simulations, local stakeholders) **Issues** • Increased situation awareness only leads to action if certain conditions exist (e.g. familiarity with climate change actions) (hybrid multiplayer game, decision-makers) • Although some players discussed with friends about the game, few participants engaged in behavior change after playing (single-player computer strategy game, unknown age)

3.5.2. Study design strength

We examined the primary studies' designs in terms of their suitability to evaluate the effectiveness of the intervention on climate change engagement. Studies were classified in three groups according to their design regarding measurement comparisons. In the high strength group, we included only those studies that reported findings on climate change engagement as part of case-controlled studies and experiments (9.4%). The medium strength group consists of before–after studies (31.2%). Finally, the low strength group consists of studies that report qualitative data and studies that measure engagement after the intervention or through quantitative data collected during gameplay but do not have other measures to compare the data with (59.4%).

While more than half of the research outputs were classified as of low strength, the fact that this is an emerging field makes this proportion expected. Considering that a goal of this review is to map the broad field of game-based climate change engagement, we have chosen not to omit those studies, but to discuss their (mostly qualitative) results according to their relative weight and specific contexts of implementation.

4. Discussion

This study mapped the extant corpus (64 papers) on game-based and gamified interventions on climate change engagement. Its scope included not only interventions specifying climate change engagement as a goal, but also those which sought to analyze currently existing responses to climate change. The inclusive search protocol and the detailed mapping make this study the most comprehensive review of this growing field to date. Our data indicates that game-based climate change engagement is a nascent and growing area of research situated mainly between the environmental and the social sciences. The literature reviewed, all published in the last decade, yields multiple promising results from heterogeneous gamified approaches in diverse situations.

Table 15. Presence of game elements and game experience results in high and medium strength papers.

Game elements	Game experience results
Achievements/progression Challenges (16); feedback (15); levels (14); points (12); quizzes (6); badges (3); increasing difficulty (3); leaderboards (2); timers (2). **Social** Cooperation or collaboration (9); competition (6); customization (3); peer-rating (2). **Immersion** Visual game world (13); stories or characters (9); avatar (8); role-play (2); in-game rewards (2). **Representation, resources, material** Physical playboard (4); in-game economy (4); debriefing (3); physical or digital objects as game resources (2); unexpected events (2); facilitators (1); real-time dependence (1).	**Preference and other benefits** • Appreciation of the game by most players (multiplayer hybrid game, multiple stakeholders) • Preference over other educational methods; appreciation of challenges and learning content, and willingness to recommend (single-player digital games, K-12 students) • Preference over other instruction methods (digital or board game played in groups, primary students) • Preference over other strategies for climate change education (gamified digital app, tertiary students) • Game considered understandable, useful, rigorous, and objective (multiplayer hybrid simulation gamifying a course, tertiary students) • Game considered a safe space for learning, reflection and sharing perspectives (role-play simulations, local stakeholders) • Game considered engaging and informative (single-player digital game, tertiary students) **Enjoyment, fun, motivation** • Excitement to play; enjoyment; fun, engagement, interest (single-player digital games, K-12 students) • Motivation and enthusiasm (multiplayer board game, K-12 students) • Fun (digital or analog game, K-12 students) • Enjoyment irrespective of intrinsic motivation towards environmental issues (multiplayer board games, adults) • Entertainment (multiplayer hybrid simulation gamifying a course, tertiary students) • Fun (gamified digital app, tertiary students) **Intense participation** • More engagement in class (gamified flipped classroom, tertiary students) • High level of attention during the game (hybrid simulation game, water managers) **Issues** • Criticism of games as a method for serious purposes (multiplayer hybrid game, multiple stakeholders) • Issues with graphics quality, lack of challenge, lack of interactivity; bugs; confusion, excessive difficulty, and lack of fun (single-player digital games, K-12 students) • Opaque game mechanics, poor scaffolding of learning (single-player computer strategy game, unknown age)

Table 16. Quality assessment mean scores.

Question	Mean	SD
Q1. Was there a clear statement of the aims of the research?	0.961	0.135
Q2. Was the research design appropriate to address the aims of the research?	0.813	0.289
Q3. Was the recruitment strategy appropriate to the aims of the research?	0.828	0.256
Q4. Was the data collected in a way that addressed the research issue?	0.703	0.342
Q5. Have ethical issues been taken into consideration?	0.477	0.326
Q6. Was the data analysis sufficiently rigorous?	0.602	0.380
Q7. Is there a clear statement of findings?	0.883	0.213
Q8. Does the research provide a valuable contribution?	0.875	0.218
Total score	6.141	1.529

In our review, we found a balance between climate science, mitigation, and adaptation. By including scientific support, that is, a reason for action, policy is more likely to be understood and accepted (Lorenzoni *et al* 2007). Game-based interventions in the sample also materialize in a variety of formats, from digital to analog to hybrid. In many cases, this indicates a conscious effort to adapt to the players' habits and needs, such as an interest for digital platforms in the case of young

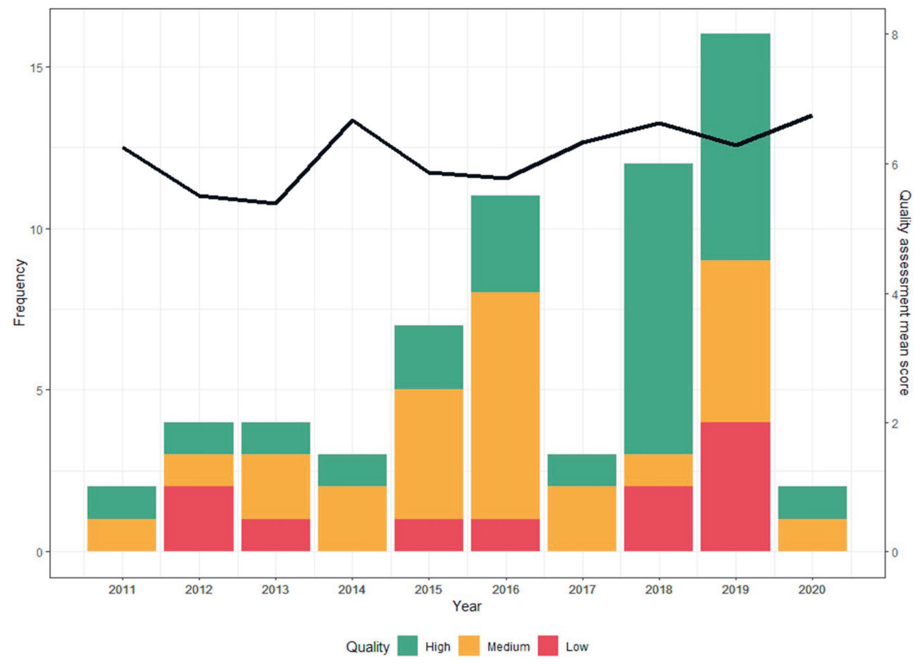

Figure 5. Number of papers by quality category, per year (bars, left *y*-axis) and quality assessment mean score (line, right *y*-axis).

students, or the adequacy of software-supported role-plays for professional audiences. In terms of design elements, the games described in the papers go beyond traditional criticisms of gamified solutions, which often present a simplistic design based on points, badges, and leaderboards (Koivisto and Hamari 2019). Here, all games included at least one achievement-oriented element, and over three quarters featured also immersion and social elements.

The vast majority of the results reported indicate that games can impact multiple engagement dimensions at the same time, as well as provide engaging and enjoyable ludic experiences. Thus, although the existence of publication bias or its extent cannot be known or measured, different game-based interventions do seem to result in participants' engagement with climate change. Cognitive engagement appears to be the most researched dimension, including all three application domains (climate science, mitigation knowledge, and adaptation knowledge). Although less numerous, engagement results in all other observed dimensions were reported.

More specifically, as a result of analyzing the papers that used systematic data gathering and data comparison analysis methods, i.e. 40.6% of the sample, multiple examples of effective implementations of game elements for climate change engagement were found. As suggested by the games and gamification background literature, climate change game-based interventions are often preferred over other methods and can provide motivation, learning through experience, safe spaces for social interaction, and visually supported engagement with complex topics.

However, we also uncovered several areas in which research and design could improve in the future. In terms of context, most contributors work in advanced economies, especially the US and the Netherlands, and conduct interventions there. Advanced economies have some of the highest per capita CO_2 emissions: according to 2016 data, OECD members emitted 9 metric tons per capita versus the 0.3 of the UN least developed countries, and the higher the country income is (not accounting for internal inequalities), the higher the emissions per capita tend to be (World Bank, n.d.). This provides an argument for interventions targeting mitigation behavior in those countries. However, developing countries are especially vulnerable to climate change (IPCC 2001), which underlines the importance of adaptation in those areas.

Regarding populations, studies seldom collect data about beliefs, attitudes and values in these areas, or even knowledge about climate change. Interpreting and adequately contextualizing cognitive, affective or behavioral gameplay results becomes difficult without a clear comparison with the players' previous level of climate change engagement. Moreover, most of the studies in this sample focus on engaging adult participants, many of which are university students, which raises doubts about the possibility of using similar engagement interventions with publics of different educational levels and ages. In addition, players are regularly framed as consumers, professionals or simulated decision-makers, neglecting other possible citizen roles.

Interventions are often short, consisting of only one session and thus limiting their possible learning impact (Wouters *et al* 2013). Despite the breadth of climate change causes, impacts, and possible measures, a few topics concentrate most of the attention, e.g. droughts, floods, economic aspects of mitigation, or climate science. Although games are generally effective in engaging players with climate change, the behaviors measured mainly occur in-game, for example through peer discussion. We also observed problems with game experiences. Players can see games as unfit for professional settings, too difficult or complex, or disconnected from their interests.

Our evaluation reveals a need for more rigorous data collection and analysis methods, better controlled designs and more longitudinal interventions. In this way, results will be more reliable, although comparability will remain a matter of focusing on specific contexts. Finally, we conclude that there is a need for more consideration for ethical issues. From the above findings we propose a research agenda in order to advance this area of study.

4.1. Agenda for future research

In this subsection, we propose a series of recommendations for future research based on the gaps and opportunities detected, divided into the same four parts as our results: contexts and populations; intervention; outcomes and results; and quality and strength.

(a) **Population and context**

1. **A larger variety of social, political and economic actors can benefit from adequately designed game-based experiences.** Unprecedented climate change mitigation and adaptation measures should be undertaken in practically all areas of society, policy making and economic practice in order to limit global warming (IPCC 2018). This potentially involves wide sectors of the global economy, at multiple scales, and thus permeates multiple areas of human daily life. Over a third of the papers involved populations that were already professionally or educationally involved with the topic. In addition, professional sectors other than farming and water management are virtually unrepresented in this sample, as are local citizens and stakeholders. We believe that a multitude of actors would benefit with a direct engagement with climate change, be it in terms of how to contribute to its mitigation through political or economic practice, or to adapt to its personal, community, and professional life impacts. Future design frameworks that integrate user-centered design principles applied to gamification (Rajanen and Rajanen 2017) with the specificities of climate change engagement could support such an effort in terms of audience variety.
2. **More information on the participants' background and valuation of games is needed.** Climate change is both a political and an environmental issue, and as such it is important to measure players' leanings in these aspects (Hart and Feldman 2016). None of the papers reviewed identified a significant share of climate contrarianism in the population, with one claiming that the potential players 'who did not participate in the workshops (four out of sixteen farmers) were the only climate-change deniers and remained uninterested' (Sautier *et al* 2017, p 547). Interventions may want to engage further those who do not hold a prejudice against scientific evidence and even show concern for climate change, focusing on the central environmental topic of bridging the value-action gap (Blake 1999). However, they could also motivate participants unconvinced about the rate of climate change and its repercussions, whose current behavior may represent higher than average greenhouse gas emissions, through technological and economic development arguments (Bain *et al* 2012). Irrespective of the target audience, it is important to understand the player's profile to gauge how the effectiveness of solutions varies according to pre-existing conditions. For example, ineffectiveness can be explained by a perceived high level of knowledge (Fjællingsdal and Klöckner 2019) or a current high level of sustainable behavior (Petersen *et al* 2019), as opposed to those with less awareness and concern to begin with (Rumore *et al* 2016). Collecting player perceptions about in-game representations of reality is also important, as extreme skepticism of a game model can seriously hinder learning (Waddington and Fennewald 2018). An understanding of the participants' history with climate change, for example related to experienced impacts that could be attributed to it or perceived relevance in their daily lives, may help interpret their reactions to game-based experiences. In addition, other relevant personal variables such as age, income, aspects of the quotidian environment (e.g. urban or rural, proximity to the coast), and geographical origin should be collected and reported to contextualize findings in themselves and in relation to other literature more precisely.

3. **We encourage researchers from all origins to look more often towards emerging and developing economies.** Climate impacts are expected to be especially dire in developing regions, which rely on agriculture and have more vulnerable populations and more limited economic and technological resources overall (Mertz *et al* 2009). We recommend more game-based interventions to be situated in emerging economies and explicitly linked to locally relevant adaptation measures. In addition, game-based engagement can help raise climate literacy so the relationship between local land use or polluting industrial activity and climate change are understood and sustainable development is embraced. We consider an optimal path involving researchers and institutions from those same countries with native capabilities, who will have, or be able to gather, the cultural and practical knowledge on the challenges and assets within these communities.
4. **We recognize the need for more research involving K-12 students.** The widely quoted definition of sustainable development as meeting 'the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development 1987, p 54) directly involves the young of today. More immediately, children are especially vulnerable to climate change and its impacts, and minors around the world declare interest, concern, and even fear of climate change (Clayton 2020). Specific coping strategies for negative affect (e.g. anxiety) can bring, or even consist of, productive engagement (Clayton 2020). Indeed, children and teenagers have gained a more public profile as activists since the climate strikes of 2019. In the reviewed literature, they have even been involved in climate action as facilitators of game-like experiences (Culén *et al* 2016). However, most of the studies in this sample focus on engaging adult participants, the majority of which are university students. As some examples in this review show, game-based engagement directed at young students can favor scientific literacy and even critical engagement with an issue that extends far into their future. Role-plays, campaigns and enquiry-based projects, examples of learning methods recommended for the UNESCO climate action learning objectives (Rieckmann 2017), can be tools to continue this promising line of work and research.

(b) **Intervention content and design**

5. **Interventions that target specific behaviors, such as energy conservation, should connect explicitly with climate change.** Through the selection process for this review, we have seen that multiple venues publish empirical studies on topics connected to climate change, such as disaster adaptation or energy saving, but they were out of our scope. Although these constitute engagement interventions, their lack of explicit connection with anthropogenic climate change disconnects them from this clear and important reason why, which can lead to failure and rejection at the level of policy (Lorenzoni *et al* 2007). Indeed, knowledge on climate change has been linked to greater concern, which increases perceived efficacy and responsibility to address its challenges (Milfont 2012). It is possible that simplified messages alluding to, for example, benefiting the environment or preventing air pollution, will be a sufficiently meaningful framing in certain contexts. Especially where the implicit connection to climate change is well understood, this will avoid overloading the player with information. In other cases, the disconnect between individual or community behavior and the global changes that they aim to address can be a lost opportunity to create broader knowledge, a deeper sense of importance and purpose, and motivate behavior beyond short campaigns and extrinsic rewards. Thus, connecting localized issues with the big picture is a strategic decision to confront.
6. **In-game actions could have real-world impacts by design.** If the changes needed to mitigate and adapt to climate change affect all areas of life, citizens can adopt multiple roles as economic, political and social actors. However, environmental action is complex and demanding. Multiple variables relate to the truly environmentally responsible citizen, including 'information, awareness, concern, attitudes/beliefs, education and training, knowledge, skills, literacy and responsible behaviour' (Hawthorne and Alabaster 1999, p 26). Furthermore, multiple barriers stand in the way between citizens, environmentally protective behavior (Pelletier *et al* 1999), and climate action specifically (Gifford 2011, Whitmarsh 2011). Gamification could have a prominent role in connecting game-based engagement with direct real-world behavior. As shown by various interventions, players can solve game challenges through real-world action (e.g. Lee *et al* 2013). These need not be limited to consumption, but could embrace the spectrum of possible public roles, from supporter to participant in science and policy discussion (Wibeck 2014). More game-based research could afford direct participation in real fora by promoting social discussion and collective action,

either through official, non-governmental, or informal channels.

7. **Extended exposure to games and combination with other methods can multiply the learning impact of game-based interventions.** Serious games are more effective in driving cognitive learning results when they span multiple sessions and/or are combined with other instructional methods (Wouters *et al* 2013). Given that most interventions were delivered in a single session, limiting the engagement time of players to a few hours at best, this longitudinal dimension should be explored further in the future, especially considering that a crucial goal of engagement interventions is promoting the understanding of a complex phenomenon comprising climate change causes, impacts, and possible actions. In the area of climate change adaptation, long games 'are more likely to create deeper player engagement that challenges existing mental models, changes player behaviour, and catalyses action by enabling players to make climate change adaptation decisions in the face of uncertainty' (Flood *et al* 2018, p 18).
8. **Games can explore the breadth of existing and potential climate impacts beyond the most known.** Many research outputs simulated the occurrence of climate impacts through, for example, randomization or unexpected events, mimicking uncertainty as a key component of the otherwise complex and ill-defined climate change issues (Rebich and Gautier 2005). However, few studies focus on specific impacts of climate change beyond those related to high temperatures and lack of precipitation (drought, desertification, increasing temperatures, and heatwaves) and floods. The impacts of sea level rise, extreme weather events, ocean acidification, disease spread, conflicts for natural resources, human displacement or ecosystem threats, to mention a few, are underrepresented. Other climate science concepts, such as tipping points, have not been referred to at all. Especially for interventions that are situated in real communities, detecting the existing or potential climate-related threats can be of utmost importance to generate a sense of connectedness to the situation on the ground. As an example, reframing climate change as a health issue has been found to make it more relevant and understandable (Maibach *et al* 2010). Thus, we recommend detecting previously unexplored frames and identifying those symbols (stories, synecdoches, and metaphors, as exemplified in Onencan and Van de Walle 2018) that will resonate with particular audiences and make familiar the intangible problem of climate change.

(c) **Engagement results**

9. **Behavioral engagement outcomes need to be measured more carefully.** Overall, the most reported engagement results were cognitive in nature, either behaviorally assessed (for example, through a test-like questionnaire) or psychologically inferred (usually self-reported or observed by a researcher). Behavioral engagement was, for the most part, in-game social interaction, as few studies reported real-world impacts during or after the intervention. Similar shortcomings in evaluating long-term and/or behavioral engagement were observed also in other reviews focused on interventions targeting more localized issues. For example, in a review of 26 articles on game-based interventions for domestic energy consumption, only ten measured real-world behavior, nine of which had a positive impact (Johnson *et al* 2017). As explained in point number 6, above, the necessary changes in real-world direct behavior could be implemented in the game design process itself. Nevertheless, they could also be encouraged and measured as a consequence of engaging with a completely fictional game experience.
10. **Data collection should be extended in time.** Related to the previous point, and to point 7, above, on longitudinal exposure to the games, it is important to understand how profound and lasting changes are, in all three climate change engagement areas, and to assess game-based interventions' effectiveness more holistically. In this review, a dearth of longitudinal research has been observed, with only five research outputs that followed up the participants. Furthermore, these studies included a form of delayed post-intervention data collection and varied in terms of topics, designs, sample sizes, and elapsed time after the intervention, complicating any possible meaningful comparison. Although resource-consuming, following participants systematically weeks and months after the interventions, especially if these yielded significantly positive results, would help understand the potential and actual magnitude of the effects. Prospective cohort studies comparing individuals with different degrees of exposure to climate change gamification interventions would also provide a deeper understanding of games' impacts.

(d) **Quality and strength**

11. **Rigorous research methods are needed to draw more reliable conclusions.** Our quality assessment suggests that studies sometimes fail to employ an appropriate data collection

method or analyze data rigorously. Some papers lack clear reporting of critical aspects such as sample size and selection, and measurement instruments. While knowledge questions are not always the best learning assessment tools (Chin *et al* 2009), using them in addition to the already common self-reported outcomes could give a more comprehensive picture of cognitive engagement. Moments of data collection are also important, with more pre- and post-intervention measurement designs encouraged. In cases in which a group discussion is part of the program, researchers should consciously determine when to collect individual feedback: doing so between the game proper and the debriefing would lead to an 'uncontaminated' account (Chin *et al* 2009) but would not take into account the socially constructed reflective knowledge resulting from discussion. In addition to identifying the roles and suitable measurements of the psychological impacts of the game experience on climate change engagement, physiological and objective behavioral measures such as eye tracking should be also defined and employed as they may be effective methods for studying and capturing engagement (Wouters *et al* 2013), although they have not been used at all in this sample. Finally, methodological soundness would benefit from explicit ethical considerations, which are often missing.

12. **More controlled designs with rigorous conditions are needed.** Some papers show strong research designs and/or high-quality reporting, thus providing examples of the kind of research that is needed. However, more experimental studies with large samples and rigorous inferential analysis methods would help assess the effectiveness of game-based climate change engagement more precisely and reliably. Even when including control groups, too often studies lack control conditions with informational content comparable to that in the games (Soekarjo and van Oostendorp 2015). If the goal is comparing games to other media, or even games in different media (e.g. Erb 2015), ensuring that this is the only variable that changes between groups, while preserving the same content material and method of instruction, is a major challenge (Clark 2001). Furthermore, even if games give a better result than a different medium, effect sizes should be considered to justify a potential game choice over an alternative that is easier to implement. For example, research on instructional effectiveness focuses on effect sizes of at least $d = 0.4$ (Mayer 2019). In addition to media comparison studies, we encourage research that helps understand the effects of isolated game features on climate change engagement. As mentioned in the results, value-added game research could be a useful method (Mayer 2019). Other approaches that would increase the strength of studies without requiring a direct manipulation of the games include controlling for player variables such as age, experiences of climate change, professional background, game preferences, or intrinsic motivation towards the environment (e.g. Gugerell *et al* 2018), or examining how players' in-game actions may correlate to engagement outcomes (Meya and Eisenack 2018). Finally, manipulation checks in experiments would help researchers determine if the game treatment is representative of the independent variable that is theorized as causing the change in climate change engagement. In this way, studies could measure both convergent validity (the intervention is perceived as intended, from general game experience indicators such as the game being enjoyable, engaging, flow-inducing, or intrinsically motivating, to particular elements such as a character being relatable) and discriminant validity (no unexpected effects result from it, e.g. an added story unintentionally reiterating content) (Highhouse 2009).

5. Conclusion

In this article, we systematically reviewed 64 research outputs that engage players with diverse climate change issues through game-based interventions. In particular, we examined populations and contexts, formal features, outcomes, and the study designs and analysis methods employed. We found that this area of research has been growing for the last decade, both in overall quantity and in number of high-quality papers. Interventions engage various populations with scientific topics, mitigation, and adaptation across the climate change engagement dimensions, while providing generally well-received game experiences. A variety of formats are used depending on the context, usually using design features that promote achievement, immersion, and social interaction.

Nevertheless, we found diverse areas in which both research and design practices could improve in the future. Based on these gaps, we articulate 12 recommendations in a research agenda that researchers and practitioners should consider in the future in order to explore the full potential of gamification for climate change engagement. These recommendations have implications in the four areas of our analysis: who do these interventions target and in what contexts, their design, their engagement results, and their strength and quality. First, in terms of contexts and populations, we propose to situate interventions in emerging and developing economies, to understand better the participants' background regarding climate change and games, and to extend the targets to young students and more social, political and economic actors. Second, interventions themselves should strategically position their content within the larger frame of climate change, design actions so they have a real-world impact, extend beyond single sessions, and tackle understudied climate manifestations. Third, to complement existing results, behavioral outcomes should be more sought, and data collection extended in time. Fourth, to increase research quality, we propose more rigorous research methods and designs.

The authors of this review acknowledge its possible limitations. Apart from the involuntary errors that could occur in coding a complex landscape such as this one, the heterogeneity of the studies in terms of populations, contexts, and intervention types has led us to offer a broad overview here. Future reviews will be able to answer more specific questions. We also provide an overview of multiple engagement dimensions, which limits the level of detail provided in reporting each one of them. Future reviews can focus, for example, exclusively on cognitive engagement outcomes, detailing different concepts articulating climate change cognitions. The conducted quality and strength analyses are focused on identifying gaps in literature to further provide recommendations for future research. A meta-analysis focusing on the relations between quality and strength and specific variables, such as the background of the participants in relation to climate change, or the engagement results of the literature, is suggested as future work. Methodologically, we rely on multiple relevant databases and complement our process with a forward snowballing search, but we did not include a backward search due to its large resource requirements and possibility of small or naught return. However, our methods allow us to assume that we reviewed an exhaustive sample of the empirical game-based climate change engagement in the last decade.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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PUBLICATION II

Avatar identities and climate change action in video games: Analysis of mitigation and adaptation practices

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Avatar Identities and Climate Change Action in Video Games: Analysis of Mitigation and Adaptation Practices

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ABSTRACT

Games are considered promising for engaging people with climate change. In virtual worlds, players can adopt empowering roles to mitigate greenhouse gas emissions and/or adapt to climate impacts. However, the lack of a comprehensive exploration of existing climate-related identities and actions prevents understanding their potential. Here, we analyze 80 video games and classify avatar identities, or expected player roles, into six types. Climate selves encourage direct life changes; climate citizens are easy to identify with and imitate; climate heroes are inspirational figures upholding environmental values; empowered individuals deliberate to avoid a tragedy of the commons; authorities should consider stakeholders and the environment; and faction leaders engage in bi- or multilateral relations. Adaptation is often for decision-making profiles, while empowered individuals, authorities, and faction leaders usually face conflicting objectives. We discuss our results in relation to avatar research and provide suggestions for researchers, designers, and educators.

CCS CONCEPTS

• **Applied computing** → **Computer games**; **Environmental sciences**; *Media arts.*

KEYWORDS

games, gamification, game-based learning, avatars, identity, role, climate change engagement, global warming, mitigation, adaptation, sustainability

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1 INTRODUCTION

The current climate crisis poses a global threat to biodiversity and societies [101] and questions the sustainability of fossil fuel-dependent societies [33]. A broad and profound cultural shift is needed to limit greenhouse gas emissions as much as possible while reducing the risk of fatal impacts [149]. This includes behavioral change regarding consumption and widespread advocacy for effective climate policies, adequate technological research, and an environmentally and socially sustainable economic system [104]. Achieving societal engagement with climate change is necessary to shape mitigation and adaptation, the two complementary approaches for reducing and managing climate risks recognized by the Intergovernmental Panel on Climate Change (IPCC) [35]. Nevertheless, lack of engagement, which goes beyond mere knowledge of the problem [100], remains a pervasive problem in effectively responding to climate change.

Among the methods proposed to foster climate change engagement, games and gamification have been highlighted as capable of promoting deep connection and interaction with issues such as adaptation and sustainable consumption [53, 73]. In the area of climate change, empirical research has shown that game-based interventions can result in cognitive, affective, and behavioral engagement [51]. Digital games in particular have advantages such as interactive and multimedia capabilities, popularity, ease of access through conventional devices, and flexibility of use beyond player co-location. However, digital gaming requires radical changes to become sustainable, given production models with embedded social inequality and environmental costs [80], consumption requiring significant energy use [103], and disposal creating hazardous e-waste [122]. The benefits of digital games are thus inseparable from the issues that they entail, from which affluent consumers are insulated. This makes climate change-engaging design, which we focus on here, only one step towards truly environmentally and socially sustainable digital games.

A crucial element for player engagement is the avatar, the figure through which players exist in digital game worlds [10]. Avatars are the primary identity cue for players [163], i.e., the main element used by designers to encourage players to take a role. The relationship that forms between player and avatar has potential attitudinal and behavioral effects [127, 164], which has been leveraged to improve health habits [8, 98, 145, 155], educational engagement [48, 85, 128], prosocial behavior [72, 120, 133], and environmental attitudes [6], among other goals. However, little is known about avatars and climate action in existing digital games and how climate change problems and solutions are presented.

In this study, we analyze 80 digital games where players can act to mitigate or adapt to climate change. We aim to answer three research questions:

(1) What avatar identity types can be found in games that include climate action, and what features relevant to previous scholarship do avatars present?
(2) What climate issues do players tackle through these different identities, and how?
(3) How does addressing climate issues relate to the game's ultimate goal?

In our results, we classify avatar identities into six types according to their goals and expected ways of behaving: **climate selves**, when players' actions directly impact the real world; **climate citizens**, when they are encouraged to incarnate fictional characters that address climate change through quotidian actions; **climate heroes**, or avatars who address climate change issues using specialized or supernatural means; **empowered individuals**, who engage in individual and collective action that can negatively impact the virtual world if short-term and personal gains are prioritized; **authorities**, who lead communities or businesses but face climate challenges and conflicting interests; and **faction leaders**, who rule a collective amidst tension with external actors and environmental issues. We also examine elements of interest based on previous avatar scholarship, such as bodies, developed characters, and customization. Next, we report how avatar identities address climate change, and if doing so represents the game's goal. We then discuss potential climate change engagement opportunities provided by avatar design and their in-game integration.

This work joins ongoing multidisciplinary efforts to understand human agency and empowerment in the face of climate change, which include games [51] but lack focus on how identities (i.e., who the avatar is, their main role in the virtual world), actions (i.e., what they do), and goals (i.e., for what purpose) may shape players' relationship to climate change through different perspectives and understandings. The study adds to recent HCI games scholarship contributions (e.g., [28, 82, 106, 108, 147]) that explore how games and technology can foster human engagement with the climate crisis. We also join the HCI community's efforts to understand the role and effects of game avatars (e.g., [8, 14, 18, 41, 48, 85, 92, 127, 146, 155, 164]) by extending them to the area of climate change.

Our contributions aim to guide empirical questions for future research; include design observations for developers based on the potential of avatar identities and other features; and provide a basis for educators teaching with games to prioritize specific identities and actions according to their pedagogical interests.

2 BACKGROUND

In this section, we introduce the central topics that concern this study: climate change and engagement with it, particularly actions that constitute mitigation and adaptation; games and gamification, especially their potential for climate change engagement; avatars and identities; and fundamental avatar aspects according to existing research.

2.1 Climate change and engagement

Climate change is a wicked problem due to its indefiniteness and lack of a definitive solution; the multiple components involved in it, including the environment, society, technology, and science; and its multiple stakeholders, whose values and beliefs play a fundamental role in determining the adequacy of proposed solutions [81]. Multiple psychological and social barriers preclude understanding climate change and turning knowledge into effective action, such as limited cognition, ideology, the force of habits, distrust of experts and authorities, and inadequate behavioral change [70, 159]. Cognition, or assimilating knowledge, does not suffice to engage with climate change. Engagement requires a deeper connection that includes affective and behavioral components as well; in other words, caring, being motivated, and taking action [100]. Engagement can manifest in the private and public spheres [159], including activism, consumption, and professional practices [142], and comprises both mitigation, i.e., reducing greenhouse gas emissions or enhancing sinks, and adaptation actions, defined as adjusting to climate risks and impacts [35].

Climate change can deeply challenge identity [110] and effective communication campaigns require an explicit discussion and rethinking of economic and political citizen roles [160]. To meaningfully contribute to address climate change, citizens need not only long-term habit change or to develop new skills, but also to be allowed to participate in decision-making [116]. Opportunities for active participation can be promoted from the top, but a public mandate is important to open and accelerate such processes. At the same time, individual engagement depends largely on the person's social and institutional context [100]. Thus, individual involvement and the opportunities provided by and perceived in the environment influence each other in complex ways, with political and socioeconomic factors playing a significant role.

2.2 Games and gamification

This article is concerned with gamification understood as the societal, cultural, economic, and technological adoption of gameful systems and practices as forms of leisure but also as methods to educate, motivate, and shape behaviors [74]. Following this definition, we pay attention to climate change in systems that use game elements in non-game contexts [38], serious games, and video games intended for entertainment. From now on, the noun "game" (or "digital game," given the technological scope of this article) will be used broadly to define the artifacts at the root of the gamification process. In doing so, we take into account recent calls to expand traditional boundaries of the term [68].

Previous literature has highlighted the potential of games for cognitive, affective, behavioral, and sociocultural engagement through elements such as mechanics, content, visual aesthetics, narratives, and musical score [123]. Arguments commonly given for using games to yield outcomes beyond entertainment include (1) visual worlds which facilitate climate change communication [139] and enhance clarity and conceptual understanding [53]; (2) interactivity in safe spaces [123] that allow players to learn through experience and inquiry and construct their knowledge, mechanisms that have been hailed as promising for climate change education [105], and gain knowledge of systems, other actors, and themselves [39]; (3) social interaction in multiplayer systems, considered an effective strategy in game-based learning [161] and climate change education in particular [105]; (4) emotional engagement through narratives that support character attachment [23], role-taking and other features that can engage learners [12] and promote empathy [13, 17, 22, 152]; (5) adaptability to player performance, providing scaffolding and facilitating experiences of flow by maintaining an adequate challenge level [123]; and (6) motivation through incentive structures such as rewards or activities that players find intrinsically rewarding [123].

Regarding intrinsic motivation, games can support people's three basic psychological needs as postulated by self-determination theory: competence, autonomy, and relatedness [134]. Various features have been found to satisfy these needs (see [162]). For example, competence satisfaction has been associated with intuitive controls and immersion [134], as well as dynamic difficulty and achievements [121]; autonomy, with avatar customization and choices affecting character and narrative development [121]; and relatedness, with social interaction [134]. Single-player games may also promote relatedness, but more research is needed [148]. Need satisfaction seems to predict game enjoyment [134], but it is especially important in utilitarian contexts such as climate change engagement and pro-environmental behavior (PEB). Empirical research has shown that people who engage in PEB tend to present self-determined motivation, which is supported by competence, autonomy, and relatedness satisfaction [34]. Therefore, games that satisfy these needs in relation to climate-related PEB, and thus support internalizing motivation, could increase real-world PEB [34]. More specifically, need-satisfying game features motivate playing a particular climate change game (with its particular climate-related identities, actions, and goals), but can also influence contextual motivation towards the climate as well (see recursive relationships in [151]), driving cognitive, affective, and behavioral outcomes.

Games have been found to effectively promote cognitive, affective, and behavioral climate change engagement in multiple contexts [51, 53]. Given that a sustainable future requires fundamental changes amounting to a "system-wide transformation" [149, p. 15], gamification can help promote values aligned with this pursuit. However, existing interventions have tended to ignore relevant audiences such as primary school students and citizens in developing economies, and typically address only some climate change impacts such as floods and droughts [51]. Design-wise, issues such as insufficient graphic quality and lack of interaction [113], excessive difficulty [156], or a slow pacing [52] have precluded engagement in some cases. In addition, research rarely comments on the importance of in-game identities.

Although most games research focuses on a limited canon of digital games [68], the arguments reviewed above can be largely applied to analog games, which can provide, e.g., immersive experiences [49] similarly to digital games [75]. However, each medium has advantages and drawbacks. For example, digital games can integrate tutorials interactively, making play easier and more immediate, and use attractive multimedia effects such as music, animation, and 3D visualization; meanwhile, board games tend to facilitate player-to-player communication [46]. In this study, we focus on digital games for various reasons—many are easily accessible with domestic equipment, namely a computer or phone, they are immediately playable if digitally acquired, some are free, and the ubiquity of single-player or online modes makes them suitable for people who cannot physically meet. Echoing others [42, 114], we also recognize their unique popularity, especially among the young, and potential to convey complex topics in novel and memorable ways.

Consequently, HCI and games scholarship has expressed interest in digital games and play for environmental issues, sometimes inspired by previous designs. Such is the case of playful technology used to engage university students with PEB [82] and student-led climate science game design [147]. Other climate change game designs have everyday actions as a core element [15] or aim to combat grief through in-game action and to support learning through need satisfaction [28]. Given that the player's perspective in a serious game is often crucial to support its central argument and desired effect (e.g., [20, 28, 106, 108]), highlighting the point of view through which reality is experienced in games through the avatar identity appears to be a valuable extension of previous work.

Despite their advantages, digital games cannot be completely appraised without their material qualities [9], including a production model that entails inequalities in both software and hardware production, with outsourced manufacturing done under exhausting and hazardous work conditions and environmental costs externalized to countries with permissive laws [80]. While the use and reuse of analog games can be virtually emission-free, the technological development associated with digital gaming involves increasing energy demand from games, devices, networks and data centers [103], with the Jevons paradox questioning the advantages of solutions based purely on technical efficiency [79]. The obsolescence of older devices results in e-waste, which threatens human health and is seldom recycled [122]. For these reasons, major game industry companies, together with the UN Environment Programme, established the Playing For The Planet alliance which includes commitments to reduce the environmental impact of gaming operations, use, and waste [7]. The organization also aims to bring climate-aware themes to mainstream games with hundreds of millions of players to counter superficial and extractive representations of nature traditionally associated with games [3, 29].

Given the importance of diverse game features for engagement and motivation, and of knowing existing games to devise interventions and develop new games, past content reviews have broadly analyzed games on climate change [114, 129] or sustainability [87, 97, 141]. More recent analyses have classified digital and analog climate change games [69] and compared the engagement potential of serious and entertainment digital games [50]. Our study complements these efforts by analyzing avatar identities involved in climate action.

2.3 Avatars and identities

This study is primarily concerned with game avatars. This debated concept can be understood, for example, as the mediator of the player's agency, a form of visual representation, a character, a customizable persona, or a vehicle providing embodied presence [83]. Others consider the avatar's stricter meaning to be that of the interface technique connecting the computer and the user's body and actions on-screen [10]. The avatar summons and represents the player, and it is through the avatar that the player integrates into the game world [10]. In other words, the player learns how to act in and inhabit the world of the game through the avatar. We take this approach (that the avatar locates the player visually and spatially on the screen and in the world of the game) in order to include games where users act upon the digital world but no personality separate from theirs exists (for example, in gamified social media apps) or characters are implied through the action (e.g., a mobile game where players touch the screen to recycle waste, or strategy games where players lack a digital body).

Having established that the avatar is the element through which the player exists in the game, we turn to the concept of identity. Identities can be seen as complex, multiple, and mutable [86], and are defined and studied differently depending on the theoretical approach adopted [158]. Here, we take identity to mean a role identity, or "the system that reflects the meaning of [formally or informally] occupying a certain social position in a particular social-cultural context" [86, p. 12]. Roles, which can pertain to work, domestic life, or any other social sphere, indicate socially expected behaviors [158] and thus provide a frame to interpret events and decide how to act [86]. However, roles also have a component of personal interpretation [27]. The self, or who one is, can be understood as a combination of role identities, some more relevant, some less so [24], in addition to the core definition of the subjectivity of experience, the perception of reality in the first person [166].

Here, we address avatars' identity, meaning that we examine not the identity of players themselves, but the one that they are invited to assume. While playing, a subjective identity separate from the player's, the ludic subject, emerges [153]. This is not too dissimilar from a projective identity [67], or the avatar understood as the mix between player and character. Given our interest in game avatars, throughout our analysis the player will remain implied according to the expectations that the game has of them [1]. Any real player may embrace the role as the designers intend, reinterpret it, reject it, and be influenced by game experiences or not.

Human identity involves a complex system of associated beliefs, goals, self-perceptions, and perceived action possibilities [86]. In games, various authors have proposed methods to disentangle players' perspectives, too. In line with role identities having a set of expectations to guide behaviors, [67] proposes the concept of "avatar as identity." The avatar's identity is defined through their goals (what they should achieve in the game) and associated norms (the rules and guidelines that determine or influence how they should achieve it) [66]. Thus, avatars frame what players expect to be asked to do and how to achieve their goals, which are core elements of their game experience [138]. For precision, we further identify the avatar's goal with the game's ultimate goal, or how players win, finish, or prolong the game [165]. In addition, given that behavior is linked to a role identity to the point that it can be seen as its end [86], we are interested in examining what actions are associated with avatar identity roles.

Contrary to real humans' complex relationship between their self and its integrating role identities, "most games construct representations of individuated, unified subjects for players to adopt within the game world" [154, p. 94] to achieve a defined objective. Therefore, even in the event that players are offered multiple role identities in a game, it is reasonable to expect that one will be identifiable as the most salient to achieve the game's goal.

2.4 Related avatar research

Facilitating the intended game experience for players is a core design issue where role-taking is central [46]. In other words, since the avatar represents a way of being in the world [66], it mediates the game experience. However, little is known of how games formally allow players to exist in game worlds [153]. This study focuses on role-taking as discursively constructed [67] and reinforced through in-game interaction and communication [46]. Interaction can occur between players and entities in the game world, with other players, and with the avatar itself, for example through customization. The game may communicate with players through instructions and narration or displaying aspects of the avatar's appearance [138], and players may also enact avatar identity features in their interactions and conversation with other players. Beyond the game itself, the player's experience involves, as is known in market research, the time before and after the encounter [90], including developer-issued messaging and participation in communities of practice [66]. Previous literature on game-based climate change engagement has recommended making use of identities that are relevant to players and their aspirations. Reflecting the human side of climate change would favor achieving an emotional connection between player and avatar, with customization being hailed as a mechanism that increases personal connection [115].

The avatar is central when considering the potential of games for learning and attitude and behavior change. The avatar is the main identity cue guiding behavior [163] which can lead to the Proteus effect, or player behavior being affected by avatar characteristics such as height or self-perceived attractiveness [163, 164]. Various explanations have been proposed for this, including a synthesis of (a) self-perception theory, or people behaving as they think others would expect them to [163], and (b) schema activation, or self-concepts becoming associated with the avatar's characteristics in a way that influences user actions even after using the avatar [127]. The Proteus effect appears to be one of the most reliable digital media effects [127], but it has been argued that the closer the player feels to the avatar the stronger the effect will be [127].

While identification with characters occurs in other media, interactivity and the fact that players solve tasks themselves can result in closer identification between player and avatar, even unconsciously, and temporally change player identity [91, 92]. Identification has been understood in various ways. Some have taken it to mean how much players see themselves as the avatar, and considered it one of the factors determining the player-avatar relationship together with attachment and instrumentality [14]. Others have expanded the term to include not only feeling as the avatar, but also with the avatar as an other, and deemed it to involve physical likeness; value similarity, actual and desired; perspective-taking; liking; and avatar embodiment[41]. Players may identify with characters that are similar to them, but also dissimilar, for example as who they should or would want to be [146]. Depending on the situation, identification may be sought after via similarity, embodiment, or wishfulness [18]. Thus, identification involves not only avatar characteristics, but also who the player is, who they like, and their aspirations.

As said, taking another's role can change both attitudes and behaviors outside of the fictional frame [164]. Avatar-based interventions have fruitfully changed health habits [8, 98, 145, 155] and created positive experiences in education [48, 85, 128]. Adopting heroic identities, having superpowers or simply showing caring behavior in games has been shown to affect prosocial behavior after play [72, 120, 133]. Embodying animals in VR can positively affect environmental attitudes [6]. Accordingly, whether avatars should be similar to the player (e.g., through customization) depends on the context and can have different effects depending on player characteristics [155]. Given the promise shown by avatars in existing literature, our analysis aims to provide a first approximation to their climate change engagement potential.

3 METHODS

To answer the three research questions, we followed a process consisting of (a) game search and screening and (b) content analysis focused on aspects of interest, listed later in this section. These procedures were completed by the first author. Four aspects of their background, which may affect how they acquire and interpret knowledge, should be disclosed. First, as a researcher specialized in games and climate change, the analyst has a deep concern for the climate crisis and an interest in games as a form of engagement with it. Being conscious of this predisposition, partly fuelled by generally promising results found in previous literature [51], they aim to maintain a skeptical attitude while conducting research. They also have previous knowledge of some of the games in the sample, which provides a degree of familiarity but mandates an effort to come to the same level of understanding with the rest. Second, the analyst has professional experience as a game designer and developer. This allows for a more intimate knowledge of the inner workings of games and can provide a fast and systemic insight as a player, but requires being vigilant against prejudice and premature conclusions. Assumptions and reading between the lines are avoided in favor of tangible examples. Third, they have undergraduate training and professional experience as a journalist, including journalistic game analysis, and in corporate communication, which provides a perspective of discourse from the sender's viewpoint and considering their intentions for the receiver. Fourth, the analyst has over twenty years of experience as a frequent player of multiple game genres, but has preferences for specific mechanics, stories, and visual aesthetics. In this study, these user biases are consciously monitored and data collected thoroughly independently of game characteristics, instead of e.g. shortening data collection due to the game being perceived as tedious.

3.1 Search and screening process

To identify the current corpus of digital games that include climate action, three different sources were used:

(1) A personal collection of climate change-related games, curated between April 2019 and August 2020.
(2) The results of a Google search in August 2020 using the string *(game OR gamification) AND ("climate change" OR "global warming" OR "climate impact" OR greenhouse OR CO2 OR emissions OR footprint OR mitigation OR adaptation).*
(3) The results of a parallel search in 21 potentially related game databases, distribution platforms, and websites (for the full list, see supplementary file 1). Search tool differences imposed custom adaptations on the search string above.

The results obtained were subjected to a primary filtering that excluded those whose title, description and graphic materials did not show any connection to climate change or climate action. The remainder were screened against the following inclusion criteria; for inclusion, the game needed to be:

- Digital
- Available for computers (Windows PC, Mac, and/or Linux) or Android/iOS and fully functioning
- In English
- Explicitly mentioning climate change, global warming, and/or greenhouse gas emissions, irrespective of the game world being factual or speculative.
- Engaging the player-avatar directly in mitigation, i.e., reducing greenhouse gas emissions or enhancing sinks, or adaptation, i.e., adjusting to climate risks and impacts [35].

The screening process, summarized in Figure 1, uncovered 80 games. Supplementary file 2 contains the complete list and thus acts as a ludography where all can be found.

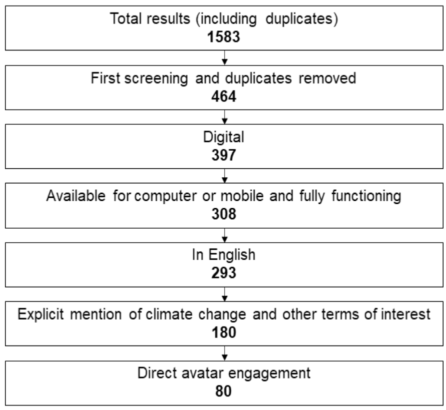

Figure 1: Game screening process.

3.2 Content analysis process

Next, we conducted a qualitative text analysis, a form of content analysis adequate for multiple cultural artifacts [93]. Its aim is to engage with the game as the "distinctive discursive moment between encoding and decoding" [55, p. 238] in order to explore its structure, symbols, and persuasive potential [55]. As the chosen method suggests, this study is concerned with games and their avatar identities rather than their audiences' reception. Although the analyst acted as a player when interacting with the games, the background detailed above tinted their experience, and their goal differed substantially from that of any implicit player. Elucidating which roles and actions are encouraged in climate change games transcends specific audience (mis)understandings or appropriations [55]. However, our discussion contextualizes our findings within other research to anticipate how the corpus of games and the ways that they represent climate action can potentially engage players.

The object of analysis includes the games themselves and paratexts surrounding them—e.g., game manuals, gameplay videos, and forum posts by players—to complement our first-hand understanding of the games. Specifically, we focused on:

- **Avatar identity**, defined by behavior-guiding norms and ultimate goals, or the states in which players win, finish, or can prolong the game [165].
- **Avatar characteristics**, including **body**, if there is one; **character**, or a separate personality from the player's; and **customization** possibilities.
- **Climate actions**, or the ways in which the avatar enacts mitigation (reducing greenhouse gas emissions or enhancing sinks) or adaptation to climate risks and impacts [35].
- **Climate issues**, either to mitigate or adapt to, and whether addressing them is the game's ultimate goal.
- **Number of players**, single player or multiplayer.
- **Spatial context**, or where the player's actions take place.

Different qualitative text analysis methods were used depending on the aspect of interest. To classify avatar identities, a type-building text analysis was conducted [94]. Given the lack of precedent regarding identity classification in climate change games, this analysis did not depart from a pre-existing taxonomy. While the literature broadly distinguishes public engagement (be it as consumers, voters, workers, etc. [160]) from the role of various decision-makers (e.g., water managers, urban planners, politicians), identities in games do not neatly map onto a binary distinction, as will be shown. Additional aspects specific to games, such as the coexistence of gamified systems proposing real-world actions and games with entirely virtual worlds, further complicate adapting these.

Therefore, we based our analysis method on Gee's argument that an identity is defined both by what they aim to achieve (or, we may say, their end) and what is the prescribed way to do so (or the adequate means) [66]. In this way, game identities with a similar goal are not necessarily comparable if the norms that they abide by are fundamentally different, and vice versa. We examined norms in relation to our particular focus of interest and purpose—e.g., does the game mention, encourage or prescribe behaviors typical of any citizen versus specific occupations; does it focus on personal versus collective action and influence; and do behaviors explicitly impact the real world. Regarding the goal, we considered if pursuing it requires climate action and, if not, whether it involves general progress and development or victory over others.

In type-building text analysis, elements, or games in this case, are clustered according to their similarities regarding relevant attributes—here, norms and ultimate goal. This results in types containing similar cases [94]. This process begins by determining the purpose of building types; in our case, our interest lies in identifying their potential for climate change engagement, which is related to (a) their similarity to the player's real identity (assumedly, that of an average citizen), (b) their potential to elicit inspiration for new action, and (c) their portrayal of the motives and perspectives of those that are dissimilar from the average citizen. Second, the attribute space (here, norms and ultimate goals) is defined, as well as the data to be assessed (verbal messages, both in-game and in paratexts, and gameplay experience of what the player can and should do in order to progress towards the goal). Third, the data is coded thematically, including messages from the games and other texts and ad-hoc descriptions of gameplay actions. Fourth, a specific method to build types is chosen. Given our need for inductive analysis, we selected polythetic type-building, which uses the empirical data directly and results in types that group games that are not absolutely equal but similar, and certainly more so than games from other groups. The resulting types are thus deemed "natural" due to their construction being based on the data. Fifth, all cases are assigned to types, which are finally described and presented.

For climate actions, we performed a thematic qualitative text analysis. First, data was coded along two main categories, mitigation and adaptation [35]. Next, the mitigation actions found were organized according to existing mitigation models and literature [32, 118, 144, 160]. For observed actions that did not fit any category, an inductive process of category building was followed, grouping multiple single observations by similarity. It is common for categories to be constructed through a mix of induction and deduction [94]. Categories and their data were re-read and contrasted multiple times to ensure that they were adequate and useful for the study, and all cases represented their categories' basic characteristics. Finally, the results were analyzed and presented.

Defining the rest of the variables required simpler processes. The player is either represented through a body or not; the presence of a character can be ascertained from a narrative background or decision-making autonomous from the player; and customization reflects whether players can freely alter any aspect of their avatar. Climate issues are determined by the avatar's climate actions—games that contain mitigation present a mitigation issue, while games in which players adapt to climate risks present an adaptation challenge. We also examined if addressing these issues is required to attain the ultimate goal. The number of players is also a dichotomous variable. Finally, the spatial context is classified inductively according to proximity to the player. Therefore, we record if the actions previously found occur in the real world or the virtual one, and if the spatial scope is personal (including the household), local (including small businesses), regional, or global.

Playing and note-taking took two hours per game on average, although this varied greatly—some required under an hour, others multiple sessions. In games in which climate change was exclusively or especially present in some parts, specific game modes were analyzed (e.g., *Power & Revolution 2019 Edition*'s [47] Global Warming scenario).

4 RESULTS

This section presents the results from the analysis, organized according to the question that they contribute to answer.

4.1 What avatar identity types can be found in games that include climate action, and what features relevant to avatar scholarship do they present?

To answer this question, we first detail the avatar identity type-building process and results, followed by other observed avatar representation concepts.

4.1.1 Avatar identity types in climate change action games. The core of the avatar identity type-building process, described at a higher level in the methods, involved five tasks [94]. First, the analyst defined the attribute space values for each game's primary avatar identity using gameplay notes and direct quotations from the games and other official sources, and joined them in a short summary. Second, they clustered case summaries by similarity, which resulted in 23 groups of games.

This clustering process involved reading one case summary at a time and reordering them in a table, placing them close to others according to how players were asked to act and to what end. Considering the purposes of our type-building, described in the methods, clusters did not mix cases where norms portrayed avatars as regular citizens with those with decision-makers, managers, leaders, or other specialists. Beyond this basic distinction, remarkably different norms and goals informing action were clustered separately. For example, in citizen-like cases, avatars encouraged to engage with different economic and political perspectives (from carbon offsetting to habit change, from voting to activism) were considered separately. The same occurred with citizen-like identities that faced mitigation versus adaptation goals. Beyond citizens, unrealistic approaches to solving environmental issues were clustered separately from those advocating the use of plausible tools, for example. Leadership identities were clustered according to the contexts that shaped their perspectives, from geographical scope to relevant stakeholders. Notably, one cluster did not lend itself to being separated according to similarity to the implied player, a delimited normative frame, and a single perspective on climate action. This cluster, the empowered individual, ended up forming its own type in the next step. These 23 clusters were given a distinct descriptive name and short phrases refining their cases' commonalities in terms of norms and goal. Given that practical relevance is a core aspect of type-building [93], this first clustering was used as an intermediate step towards a grouping that, while meaningful, was easier to apply and discuss. Supplementary file 2 contains the steps throughout the process, from game-specific norms, goals and summaries to the first clustering and the final result.

After this preliminary clustering, the third step consisted of building the final types (Table 1). This final clustering took into account the purpose of the study as well. Accordingly, the analyst grouped the newly refined norms and goals into similar groups once again taking into account citizen similarity, inspiration of new behavior, and depiction of non-citizen perspectives. This resulted in six distinct types, each of which was given a creative and descriptive name as recommended [94]. We describe them next, along with representative examples.

Nine games have **climate self** identities. Here, the implied player is expected to commit to or take actions with an environmental impact in the real world. In line with both understandings of the self described, action occurs in and as the first person and is expected to involve the player's own identity system, since their own real behavior accomplishes the goal. In other words, their life is gamified through, e.g., habits to reduce their carbon footprint (*Earth Hero* [78]) or offset their emissions (*Capture* [31]), participation in a social community (*We Don't Have Time* [2]), or the opportunity to vote for political priorities (*Mission 1.5* [124]). In all cases, the actions proposed make use of commonly accepted social, economic, and political democratic channels. For example, *We Don't Have Time*'s [2] terms of use ban violent and abusive content and request adherence to "applicable law."

Four games include a **climate citizen** identity in a fictional world. Their goals require quotidian actions requiring no special skill or status such as recycling, saving energy at home, having conversations, or emigrating after extreme climate impacts have made life too difficult (*The Climate Trail* [59]). The main norm regulating their behavior is their use of tools that are available to common citizens, no matter how imaginary or metaphorical the situation is. For example, the avatar in *Overcome Your Weaker Self* [84] must chase their weaker self, a ghost who turns on lights and drops trash. While the situation is surreal, the player just turns lights off again and collects waste.

Avatars in the next 21 games are **climate heroes**, that is, individuals who must attain climate-related goals using specialized tools (tools which a professional would have access to and know how to use but a layperson would not, such as an airplane) or supernatural powers. Even the most average-looking heroes, such as *Mad Parallax: Jumpy Road*'s [56] teenage protagonist, have access to special means and skills. In other games, diverse professionals achieve mundane goals by using uncommon expertise or fantastic skills, such as throwing light bulbs out of a plane, traveling back in time, or communicating with animals. Finally, one avatar (*Zero Carbon, Zero Tolerance* [157]) uses an armed plane to take down private jets and oil company balloons.

Three games have **empowered individuals**, who operate in multiplayer sandbox-like environments where they act as individual citizens (having, for example, private property) but can also engage in productive activity and make political decisions that influence community life. In *New Shores* [54], players win by obtaining points through actions that develop their status and that of the community. In *Eco* [65], players must develop society and technology to stop a meteorite that will collide with the planet in 30 days. In *Minecraft GlobalWarming mod* [126], players prolong the game by mining, crafting and surviving hunger and monster attacks. However, in all three cases, selfishness in production and consumption, and lack of cooperation, can lead to a tragedy of the commons [77]. Excessive greenhouse gas emissions result in rising sea levels and other climate impacts, such as ecosystem deterioration, which stall player progress and ultimately lead to pyrrhic victories. The normative frame, which encourages a balance between the individual, the community, and their environment, is largely procedural [19]—the game allows unsustainable actions, but they lead to undesirable consequences (including between-players punishment mechanisms).

The last two categories are closely tied to ample resource management and leadership. The 34 **authority** games put players in power as leaders and decision-makers in defined territories, from towns to entire planets, although they can have internal opposing forces (e.g., rival political parties, or citizens with particular interests). Although their ultimate goals are varied, from growing a business (*Oil Eco Factory Tycoon* [96]) to decarbonizing major world economies (*Power & Revolution 2019 Edition* [47]) or winning a referendum (*Deal: A Green New Election* [43]), economic growth or citizens' well-being are conditioned by mitigation or adaptation challenges affecting a community or company. Norms indicate that

Table 1: Avatar identity types

Group (n)	Norms	Goal
Climate self (9)	Real-world citizen-like behavior, including democratically available mechanisms.	Address real-world climate challenges.
Climate citizen (4)	Citizen-like behavior in a fictional world, including democratically available mechanisms.	Address climate challenges in the game world.
Climate hero (21)	Access to specialized or superhuman means, focus on the individual agent's behavior.	Address climate challenges in the game world.
Empowered individual (3)	Combination of citizen-like norms, such as action through consumption, and specialized ones, such as goods production and political influence. The avatar is an individual agent but is encouraged to negotiate with others and to protect the environment, which is affected by player action.	Pursue individual and/or collective development, in some cases leading to victory over/with others.
Authority (34)	Specialized means giving large power over a collective or organization. The power is limited by multiple interests and/or environmental issues.	Pursue community or business development. In most cases, this requires directly addressing mitigation and/or adaptation challenges.
Faction leader (9)	Specialized means giving large power over a collective or organization. The power is limited by tensions with other leaders (addressed peacefully or not) and environmental issues.	Reach victory over/with similar external entities.

players should attain their goals through decision-making powers vested on them and/or skillful resource management.

Finally, the nine **faction leaders** are encouraged to seek victory over opposing external forces. In these games, players lead a community, often a unique civilization, to rise over rivals of similar force and capabilities. These games typically contain one or more of the 4X that define the eponymous strategy games sub-genre—norms allow them to explore, expand, exploit, and/or exterminate. Despite this, goals do not always depend on conflict: diplomacy and even peace agreements are common, and some games do not include direct aggression as a tool to solve disputes.

4.1.2 Bodies, characters, and customization as relevant avatar features. While avatar identities can be categorized in the preceding six types, we now pay attention to three aspects that define how these avatars are presented—bodies, characters as separate personalities from the player, and customization—and multiplayer features.

It is not always the case that the avatar's body is explicit in the analyzed games. This is most clear in **climate self** games, where the action largely occurs in the real world and only profile images at most represent players' presence in the virtual world. **Climate citizens** do not always have a body, either; one character is visible, but two are only described, and one is implied through player actions. Conversely, most **climate heroes** have visible and controllable bodies, although they can be hidden within a glider or given a name by the player despite having one predefined appearance. Still, many do not provide a visible corporeal interface for the players' actions. Two **empowered individuals** have a body for third- or first-person play. Of the 34 **authorities**, two are verbally described and one gives the player a body only in secondary action segments of the game, while the rest only have a portrait at most. Finally, as is usual in strategy games, no **faction leader** performs through a body, but five games provide preexisting character portraits.

Across the sample, very few games offer more in terms of character than an empty husk. By definition, **climate selves** have no character background separate from the players' themselves. Neither do **climate citizens** nor **empowered individuals**. Only six **climate hero** games offer a significant character background story and narrative autonomy from the player. Three **authority**-type identities include passing references to the avatar's past or personality, while two **faction leader** games (*Civilization III* [61] and *Civilization VI* [62]) offer the option of incarnating a historical figure, and each *Alpha Centauri* [60] faction has a charismatic leader.

It is worth noting that overall, 14 games (four with a **climate self** identity, all three that have an **empowered individual**, and seven with a **faction leader**) have multiplayer features. Avatar customization options are most common in these three groups, although they rarely go beyond names and limited aesthetic choices. Some **climate self** games allow players to choose usernames or portraits. The avatar's name can be chosen in just one **climate citizen** game, and two **climate hero** games allow players to enter a name or color. Empowered individuals in *Eco* [65] and *Minecraft* [126] can customize in detail their appearance and in-game capabilities. While **authority** games typically allow players to express themselves through decision-making, only 10 include explicit avatar customization options. Meanwhile, all but one **faction leader** can be given a name, a portrait and even a civilization to lead, and players usually have multiple options to choose their actions.

4.2 What climate issues do players tackle through these different identities, and how?

We now focus exclusively on the environmental problems represented in the games analyzed and the climate actions that players can take to confront them. In the sample, we find both mitigation, when avatars act to reduce sources of greenhouse gas emissions or enhance sinks (here, we include public advocacy as well), and adaptation issues, when they can adjust to climate impacts [35]. Figure 1 in supplementary file 3 displays the divide between mitigation, framed as a problem that requires citizen and decision-maker action alike, and adaptation, which **empowered individuals**, **authorities**, and **faction leaders** are more likely to face.

4.2.1 Climate action: mitigation and adaptation. Our thematic analysis of identity tools and skills resulted in seven categories of mitigation actions (70 games, see figure 2 in supplementary file 3), which we list with supporting resources when they have not been formed entirely inductively:

- Lifestyle, related to personal transportation, home, diet, or offsetting of personal emissions [118, 144, 160].
- Public participation, or bottom-up or peer-to-peer discussion processes [160].
- Technology, or the implementation of technical improvements in transport, buildings, manufacturing, food production, and carbon capture and sequestration [118, 144].
- Energy, or the use of reduced greenhouse gas emitting methods, such as renewable energies [118, 144].
- Policymaking, including taxes, incentives, emission quotas and targets, other policies, and diplomacy [144].
- Nature-based solutions, or "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [32, p. 5] (e.g., forest protection, green infrastructure).
- Violence, when mitigation uses harmful (to people, physically or psychologically), unwanted, intentional (in some cases, even without intent to harm), and nonessential (e.g., not in self-defense) behavior [76].

Climate self games focus player efforts predominantly on personal lifestyle choices, with two of them (*CO2 Cards* [25] and *Capture* [31]) offering offsetting schemes for users to donate to real-world projects that reduce greenhouse emissions via technology, energy, and nature-based solutions. Other games proposed direct technological actions (acquiring an electric vehicle) or generating renewable energy at home. Seven of these games also propose planting trees. One game, *Mission 1.5* [124], allows players to vote on mitigation actions that they would like to see implemented in the real world. This is one of five games in this group that propose real public participation and social organization mechanisms. Meanwhile, the three **climate citizens** can either act on their consumption (by recycling and saving household energy) or practice public advocacy (*World Saver* [117]), while **climate heroes** complement measures seen in the previous two categories (including heroes who may save the world by recycling) with the implementation and promotion of technological and energy solutions. **Empowered individuals**, due to their dual role as citizens and decision-makers, present versatile skills covering both individual actions (mainly in the form of restraint in consumption) and policy-like mechanisms such as negotiation, laws, taxes, and sanctions for polluting. **Authorities** and **faction leaders** present technical, energy, and policy-related mitigation tools, and it is more common for **authorities** to implement nature-based solutions (typically, afforestation).

The use of violence for mitigation, present in five games, stands out as distinct from other categories. One **climate hero** game (*Zero Carbon, Zero Tolerance* [157]) proposes violence against polluters, as do three **authorities**. In *Global Warming Strategy Game* [57], players can use military resources to cause political regime changes, *Climate, Please!* [125] players can pick up citizens to make them bike or eat vegetarian food, and *Fate of the World: Tipping Point* [131] allows players to become villains by secretly sterilizing the population or release viruses to commit mass murder. Although violent conflict is permitted and even encouraged for many **faction leaders**, it is rarely a direct mitigation tool. Players in *Alpha Centauri* [60] and the *Civilization* saga can go to war to stop polluting rivals, but only *Call to Power II* [4] features extensive brute force mechanisms to curb emissions and punish unsustainable behaviors.

Adaptation is represented in 34 games, and practically missing from the first three identity types (see figure 1 in supplementary file 3). The only **climate self** featuring adaptation (*Mission 1.5* [124]) frames it as a matter of policy, a **climate citizen** game (*The Climate Trail* [59]) depicts a migration, and one **climate hero** (*World Rescue* [40]) addresses agricultural adaptation through measures such as new farming practices and technology. All **empowered individual** avatars can adapt to climate impacts by devising, producing and using physical defenses or purchasing protection, while open communication and commerce features allow dynamic and peer to peer collaboration. Most **authorities** can adapt their communities through political decision-making and research, and in some cases players can act to protect animals to cope with climate impacts. Finally, **faction leaders** directly produce adaptation defenses and can often remediate degraded environments, although one (*Anno 2070* [132]) cannot explicitly protect its faction from climate impacts.

4.2.2 Spatial scale of climate action. Of the 80 identities, 36% engage in personal or household-level behavior, 42% act locally, 44% regionally, and 52% globally, with 52% combining at least two of these and 38% specifically including both personal or local actions and regional or global ones (see supplementary file 2). All nine games where the player embodies their **climate self** propose mitigation action in the real world, always at the individual or household level but in five games complemented with international collective organization or direct impacts beyond the player’s immediate environment (e.g., offsetting projects). The only game featuring adaptation to climate risks does so by proposing national-level policies (*Mission 1.5* [124]). Of the four **climate citizen** games, two portray realistic individual actions, one combines local and global advocacy, and one simulates a regional migration. Twelve **climate heroes** mitigate at the individual level, nine at the local level, four address particular regional concerns, and 67% show explicit global consequences. All **empowered individuals** can engage in individual mitigation behaviors, but the consequences are felt across the virtual world, either islands or entire planets. Meanwhile, **authorities** act typically over local, regional, or global spaces that they control, often combining global and region-specific actions. **Faction leaders** usually operate in large spaces where decisions can affect particular cities, regional ecosystems, and global climate change. In general, we observed that actions at higher levels (e.g., region-wide regulations in [130]) tend to impact or target lower levels (e.g., household activities and their carbon emissions).

4.3 How does addressing climate issues relate to the game's ultimate goal?

Games vary in their identification between ultimate goals and climate action. In all of the games that have a **climate self**, **citizen** or **hero** identity, the goal is directly connected to either mitigation or adaptation, and failure to comply results in halting progress, preventing the player from finishing, or defeat. For **empowered individuals**, however, living sustainably is not a necessary condition to win; rather, unsustainable activities are punished via climate impacts that stand in the way of achieving goals, but do not make them impossible. Indeed, *New Shores* [54] players are expected to balance private and public thriving to win without destroying the environment in the process, while *Minecraft GlobalWarming mod* [126] players can materially progress, but overshooting results in collective loss. *Eco* [65] players need to progress their economy enough so they have technologies that allow them to stop a meteor, so maintaining the well-being of ecosystems and the sea level at bay is not enforced. In all three cases, the developers state in game instructions and guides that the expectation is for players to realize that disregarding ecology leads to undesirable consequences.

Meanwhile, 82% of **authorities** formally require players to address climate change issues to win. They may, however, be permitted to enact non-sustainable policies or ignore adaptation temporarily, but they can be ultimately defeated or receive a bad rating as a consequence. For example, players can finish *Climate Challenge* [130] with a low environmental score, but receiving a final message that reads "You've left the Earth in grim condition" can be hardly seen as a victory. Even in **authority** games where climate action can be ignored, climate-related issues still significantly affect the gameplay experience. It is also worth noting that various **authority** games include influential agents that dispute eager climate action, either private corporations (*Project AURA* [64], *Climate, Please!* [125]), voters (*Democracy 3* [63], *Climate Challenge* [130], *Climate, Please!* [125]), newspapers (*Climate Challenge* [130]), denialist constituents (*Adaptive Futures* [109]), consumerist or materialist populations (*Fate of the World: Tipping Point* [131]), or political parties (*Power & Revolution 2019 Edition* [47]). These diverging opinions can impose moderation lest players be ousted, and represent the need to balance conflicting goals, usually some form of economic or social prosperity while taking care of the environment.

Faction leaders' pro-environmental behavior depends on their own judgment, and in narrative terms, certain factions favour environmental sustainability more than others. Growth brings victory closer, but it tends to increase climate change through, for example, industrial and urban development or cheap, productive, or easily accessible fossil fuel energy. Although negative consequences include climate impacts and antagonistic public opinion, these have different degrees of importance. In *Keep Cool Mobile* [26], high emissions lead to serious consequences for everyone, while *Call to Power II* [4] allows players to deactivate pollution altogether. In other games, climate impacts can even be beneficial if they affect an unprepared rival (*Alpha Centauri* [60]), and even be overcome altogether through perverted logic: in *Something Something Climate Change* [37], players can agree to halt climate impacts or outpace sea level rise indefinitely by building infinitely tall towers.

5 DISCUSSION

In this section, we explore the identity types, actions and issues' potential for climate change engagement, discuss our findings' implications for researchers, developers and educators, and acknowledge the limitations of this study.

5.1 The potential of climate change avatar identities

Games have been found to support both motivation [134] and climate change engagement [51], but the role of the identities adopted by players is an understudied area. Given the potential of avatars for player attitude and behavior influence, including the provision of new perspectives [137] and practice of "mastery and control" [67, p. 98], adopting different identities would allow players to internalize their motivation towards the climate in different ways, since each one has different values, capabilities, and goals. Our study provides a first stepping stone for future researchers wishing to empirically examine and compare how players experience different climate identities. While some of the games in this sample have already been empirically studied [11, 45, 52, 102, 107], we lack detailed knowledge on the cognitive, affective, and behavioral climate change engagement effects of the rest, and of identities in general. According to observations from prior literature, all six primary avatar identity types identified contain potential benefits in terms of climate change engagement that should be studied further.

Climate self identities represent the most immediate connection between players and avatars. These games directly encourage players—the titular self—to make changes in their daily lives and often include mechanisms that could ameliorate players' environmental amotivation, such as autonomy and aid in integrating behaviors in their daily lives. Other avatar identity types could also foster a sense of competence through specific knowledge and skills [119]. However, this should be closely studied and games would need to reach those who are not already motivated. Similarly, most players should be able to readily understand **climate citizens**, their norms, and their pro-environmental goals. Future research should take into account to what extent players identify with these and consider transferring their in-game actions to their lives.

Although **climate heroes**' behavior cannot normally be imitated in daily life, realistic heroes often take action that people could do as part of their professional lives [142]. Even when dissimilar from the player, empirical research on heroes suggests that they can still inspire and motivate to uphold the values that they represent [89]. In the area of climate action, familiarity with Greta Thunberg has been shown to predict efficacy and intention to engage in activism [135], which has been dubbed "the Greta Thunberg

Effect." What and how video game **climate heroes** can inspire players to do more for the environment is also an open question. For this to occur, these games should also become highly popular.

In a different way, **empowered individual** identities also resist an immediate identification with the norms and goals of plain citizenship, but their combination of individual actions and multiplayer deliberation can be adopted by anyone living in a democratic society [160]. Through their focus on simulating the tragedy of the commons [77], these games can bring players closer to ecosystem exploitation issues. They are also especially suitable for education, since they can be accommodated in ways that increase their effectiveness—combined with other instructional methods and played in multiple sessions [161]. Still, educators may also be interested in other identities depending on their topics of interest.

This leads to **authorities** and **faction leaders**, who often belong to larger organizations. While they are the furthest away from the individual sphere, players can explore issues of diverging interests in complex social and physical scenarios and the need to reach agreements, as previous climate change games that favor perspective-taking and the understanding of others do [51, 53]. While **authorities** emphasize negotiation between a leader and subordinate stakeholders, **faction leaders** present bi- or multilateral relations as typically seen in international negotiations. As with **empowered individuals**, exploring how multi-stakeholder situations affect player cognition and affect towards climate change would be a valuable research avenue. Similarly to **climate heroes**, future research may also focus on how these identities connect to some players' professional roles or fulfill desires for idealism, which increases task engagement and enjoyment [136].

Considering growing attention towards climate anxiety/grief [30], and despite the incipience of its research, it is important to mention that the participation of **climate selves** in gamified social networks could help players who experience negative emotions express their feelings and feel understood, especially if their immediate social environments are not receptive, which may be a beneficial way of coping [30]. Direct engagement in climate action through **climate selves**, and imitable actions from other avatar identities, could also ameliorate affective issues, although it may not help those greatly upset [30]. Future games combining virtual worlds and experiences in nature may also ameliorate distress [30]. It has also been observed that children positively cope with climate anxiety through, for example, trust in societal actors such as scientists [111], which has implications for **climate hero** identities, and hope based on solutions [112], which is relevant for any game where they can engage in climate action. At least one existing game-based research project (involving an **authority**-type identity, as we interpret from the text) aims to ameliorate climate anxiety, but we lack empirical data [28].

This study also provides commentary on pre-existing designs that the growing number of climate-interested developers [150] can consider and build upon if they have climate change engagement in mind. Given the scarcity of **climate citizens** and **empowered individuals**, we issue a call to explore how these identities could provide engaging game experiences. We understand that in the case of **empowered individuals**, having to develop a complex multiplayer ecosystem (or agents with artificial intelligence) may be a barrier, but *Minecraft GlobalWarming mod* [126] suggests that existing games can be modified and *New Shores* [54] demonstrates that 2D graphics can be used. Game creators may also attempt to break free from the observed types by hybridizing them or envisioning new perspectives.

5.2 Mitigation and adaptation in games

In terms of mitigation, it is encouraging to see that **climate selves** engage in a multiplicity of actions represented in the public engagement literature [142, 160], rather than just being framed as consumers. Nonetheless, the small number of **climate citizens** and variety in their actions points to gaps when it comes to representing "regular people" identities in climate action games. Meanwhile, examples of most mitigation action categories can be found in the rest of identity types, which once again is encouraging for educators seeking particular representations in games. On a different note, researchers are encouraged to examine in more detail the portrayal of salient climate actions such as policy, violence, technology, and nature conservation, for example regarding their level of scientific fidelity and the degree of choice allowed for action and strategy. This can even include games that feature pro-environmental topics but do not frame them explicitly as addressing the climate crisis.

The explicit use of violence as a tool to support mitigation is a rare albeit intriguing discovery. Given the use of terms such as "eco-terrorism" for actions that, while illegal, target property and financial loss [99], the exploration of these topics through video games can play a role in clarifying players' interpretation and positioning towards different forms of climate activism. For example, players of *Animal Club* [143], a mobile game for children, must stop tree logging by tapping on chainsaws to save an Amazonian sloth. This action, reminiscent of civil disobedience actions such as tree sitting, could result in arrest in the real world, but does not constitute violence according to our definition. The nature of military conflict connected to adaptation in the form of competition over dwindling resources, as can occur in most **faction leader** games, is also worth debating. We should also mention *The Carbon Neutral Republic of Novaya Zemlya (Inc.)* [58], where players fight the Russian state to establish a colony of climate refugees in its territory. Is Russian aggression to defend its sovereignty essential, or are the activists using essential force to protect refugees' lives? By facing wicked moral problems [140] in the context of wicked climate change, players can explore the ethical tensions related to climate action, which will rarely produce an immediate, incontrovertible, and unique solution, and where even good-willed action can have unforeseen negative ramifications. According to Goerger [71], the morality of violent games can be evaluated through their content, especially what values are cultivated or disrespected, and the social context of violent acts (for example, whether it is similar to real situations or not). Given the transient nature of values, games should be debated individually and taking into account the social context that gives meaning to the violence, although the violation of social norms should not be automatically viewed as violent [76].

Regarding adaptation, we observe a similar presence in an analysis of 52 serious digital and analog climate change games published in 2013 [129] and ours. While the samples are not entirely comparable, we found similar proportions of games depicting mitigation (over 85% versus our 87.5%) and adaptation (38.46% versus 45%). A recent analysis of digital and analog games [69] found an even smaller percentage of adaptation games, 20%, despite the growing importance of adaptation to climate risks. Furthermore, the aggregate data suggests that in virtual worlds, adaptation is largely associated with those in charge, while multiple profiles and communities can benefit from game-based engagement with adaptation [53]. Therefore, game developers are invited to conceptualize adaptation stories where the citizen point of view can be adopted meaningfully, for example as local community member.

According to Sheppard [139], effective climate change communication should be local, visual, and connected (linking issues and solutions, the local and the remote, the past and the future). The fact that 68% of identities engage in personal and/or local actions, and 38% combine personal or local actions with regional or global ones, suggests that multiple existing games have potential for local and connected messaging, apart from the obvious fact that almost all offer visual representations of climate change. Games can make tangible the abstract and the distant, two major climate change features that hinder engagement, and thus combat apathy and paralysis [29].

Finally, we observed that neither **empowered individuals** nor **faction leaders**, nor a few **authorities**, made fighting climate change the winning condition. This offers players a larger degree of agency and provides information rather than enforcing a certain behavior, which can not only support autonomy [88, 134] but also still constitute a persuasive argument [19] for climate action. In the board game version of *Keep Cool*, it was found that players who chose climate-damaging technologies in the game became more politically optimist, which suggests that open experimentation instead of a single normative path to victory can lead to learning and attitude change [102]. Notably, players adopting an identity different than their real one may have supported learning [102]. Developers should take into account that enforcing pro-environmental behavior in games is only one possible choice to support climate change engagement, and not necessarily always the best one.

5.3 Contributions to avatar scholarship and implications for researchers, designers, and educators

Next, we discuss the implications of the avatar representation concepts examined—bodies, characters and customization—, comment on the applicability of our results beyond digital climate change games, and summarize recommendations for researchers, designers, and educators.

Previous literature typically conceptualizes the avatar as the user's visual representation and examines effects based on its appearance [127]. Although this study does not focus on representational aspects to build its types, and in fact considers a broader definition of avatar altogether [10, 83, 153], we have noted the presence of bodies in the games analyzed. The scarcity of playable figures in climate change games, most of which are **climate heroes**, reveals a potential difficulty for studying Proteus effect-style media effects involving various avatar identities. However, other games offer portraits which are also visual representations, albeit not controllable bodies, and can be used as identity cues. Bodies and portraits could be compared to a total absence of visual identity cuing to better understand their effects. In fact, conventional perspective-taking role-playing is cited as an antecedent to the Proteus effect [164]. Also importantly, only two games were available for VR (*Trash Time* [16], *Cleanopolis* [44]). Future research could compare the effects of avatar identities in VR and traditional screens.

Having a character narrative background is another relevant factor for avatar use in HCI. Again, very few avatars have a developed personality outside of the player's. Given that avatar identity can be communicated through narrative elements besides appearance [138], it is important to establish how self-perception occurs when identity cues are not visual but, for example, verbal. Future studies can explore these, while acknowledging that avatar identity narratives will result in different degrees of identification/perceived closeness by different players.

Furthermore, even without an explicit character-establishing narrative, avatars can be perceived as representing a role that players recognize, e.g., a soldier or a car pilot, which already can have an effect on them [92]. Indeed, abilities may be enough to suggest who the player is, driving norm-appropriate behavior [120]. This suggests that conventionally recognizable roles and skills are relevant avatar concepts together with identities, bodies, technological immersion, and narrative background.

Avatar customization has been highlighted as fostering personal connection [115] and promoting game enjoyment through autonomy and control [88]. Aspects such as customization and gender consistency affect perceived closeness [127], which has been qualitatively linked to Proteus effect strength [127]. However, most **climate citizen**, **climate hero**, and **authority** avatars lack customization options. We suggest a more extensive use and comparison of customization options in connection with various climate-relevant avatar identities in research and design.

Embodiment and customization can augment the Proteus effect [127], but user-avatar closeness can also be fostered through emotional connection. Identification can occur without customization or even interaction [91, 92], and even without similarity with who the player is at the moment [41]. These aspects of avatar personality, which can be communicated and enacted in visual or verbal ways, can have important implications if we take identification as a broad phenomenon involving concepts such as desired value similarity and liking, as suggested by some [41, 146]. Furthermore, similarity and dissimilarity can have desired or undesired effects depending on the situation [155], which leaves an open door for all identity types to have a role in engaging with climate change.

Overall, this discussion points to the fact that avatar identities, regardless of their representation modes and similarity to players, can have effects that should be explored further, in the area of climate change games and beyond. Given frequent conceptual openness, future empirical studies should define precisely what is meant by avatar and important keywords such as identification, and identify clearly the elements at play in constructing the avatar identity. Since the user-avatar relationship depends largely on the player, it is also important to carefully understand who the player is, or at least whether they see themselves as similar, identify with, and/or feel close to the avatar. While reflections about our avatar identity types and their potential for connection with players can be climate change-specific, generic aspects such as bodies, characters, and customization are rather universal.

In fact, these types may be tested in game contexts outside of climate change. Confronting a real-world issue through real-world actions, virtual citizen action, heroically or using special skills, as a versatile actor, or as a decision-maker, either in a contained space (however complex) or among other self-interested similar forces, hardly applies to climate change or environmental issues alone. The use of these types in other contexts offer exciting opportunities to discuss how the role identities suggested in games could persuade of how issues should be addressed.

In addition, given digital games' environmental impact, we encourage researchers to investigate when their creation and use may be truly justified, for example through media comparisons involving role identities in analog formats and avatars in digital worlds. Environmental burdens can remain largely invisible to players; thus, it is crucial to question whether and how digital games can do more good through engagement or altruistic schemes than harm in terms of environmental and societal sustainability. With explicit mentions of analog role-playing as affecting self-perception and grounding Proteus effect research [164], and the many relationships that role-players establish with their characters [21], the potential of tabletop and live-action modalities may not be too dissimilar from digital avatar-based play. However, irrespective of the medium chosen, a sustainable future requires fundamental technological, economic, and sociopolitical changes [149]. Gamification can only be a tool towards this goal and designers should be mindful of the changes required beyond incremental improvements, and the need to involve audiences beyond Western adults [51].

To conclude our discussion of the results, we summarize contributions and implications for researchers, designers, and educators. For researchers, we have provided six types of avatar identity and a dataset detailing climate action in existing games. These tools can help them address the following recommendations:

- In empirical studies of climate change game effects, consider the contribution of avatar identities to game experience and engagement, either in isolation or by encouraging players to face the same issue from different perspectives. This can include cognitive, affective, and motivational-behavioral aspects. Some possible questions are:
  - Do **climate selves** have motivational and behavioral engagement potential? In what conditions, and for whom?
  - Can **climate citizens** articulate relatable experiences in a safe space for players to learn and rehearse? How can this knowledge transfer outside of games?
  - Do **climate heroes** promote inspiration and wishful identification, and if so, how?
  - How can **empowered individuals** help understand the opportunities and challenges of deliberation to address common ecological problems?
  - Do **authorities** help players understand the position of the decision-maker who must consider stakeholders?
  - Do **faction leaders** effectively represent multi-lateral negotiation and affect views such as confidence in politics?
- Further explore the role that variables such as body, narrative character development, or customization in climate change games can have. What are the climate change engagement effects of different forms of identity cuing and degrees of self-similarity?
- Investigate player views on the role of violence in polarized and polarizing topics. Can games become proving grounds for experiencing and discussing authoritarian and radical approaches to wicked problems? What can games reveal of player values, and how do they affect them?
- Notice that almost no **authorities**, and neither **empowered individuals** nor **faction leaders**, must address climate change to achieve goals. How do player perceptions change when they are enforced to successfully face a climate crisis versus when they are not?
- Be mindful of games with multiplayer modes and different spatial configurations. What are the effects of playing among humans versus alone? What are the effects of games with different geographical scopes, from the local to the global?
- Finally, we suggest two further explorations of these avatar identities. Can they be meaningfully applied beyond climate change games? Can they be used beyond digital games?

Designers can also use the types and dataset to:

- Derive inspiration and, if designing a game with utilitarian purposes, consider the potential of each identity type.
- Address the existing scarcity of **climate citizens** and **empowered individuals**. For example, how can meaningful game experiences that are closer to the citizens' be designed?
- Explore avatar representations that make use of bodies, narratives, and customization options, both because of their engaging qualities and because of their potential for effects beyond entertainment.
- Consider if more adaptation-centered games can be created from the point of view of the citizen, given the increasing need for disaster readiness.
- Design with under-represented tools and perspectives in mind. For example, participation is rarely used as a mitigation tool, and wicked situations are by definition too troublesome and complex to be addressed through only one perspective or way of acting. In this sense, mixing avatar identities in the same game can be enriching.
- Consider what the added value of using a digital medium is and ways to minimize the impact of game production, use, and disposal, including environmental sustainability but also societal concerns. Be wary of advocating for incremental change exclusively.

Similarly, the types and dataset can be used by educators to:

- Select the games that they want to use based on the avatar identity, actions, number of players, and scope of interest.
- Identify games for learning, but also for discussing attitudes, affective relationships to issues, responses, places, and people, and to experience and discuss their motivational effect or intention. What do students think about topics and identities, the games themselves and their use for serious purposes?

5.4 Limitations

One important limitation of this study has been the use of a single analyst. While in qualitative text analysis it is recommended to use two or more coders [94], we argue that the position of the analyst as a player, researcher, journalist and designer of climate change games provides a valuable perspective. While idiosyncratic, this particular collection of identities, to use our topic's term, should be able to offer a comprehensive and coherent observation and interpretation of games' discursive attempts to position players within the game world and persuade them to participate as intended. On the flip side, to address the inherent limitations of using a single perspective, we paid special attention to our category definitions and the explanatory examples used, as advised [94]. We also used additional strategies [36] adapted to the analysis of games [95] to ensure the accuracy of the data and our analysis, including examples and detailed descriptions of the concepts presented, as well as possible exceptions, to support the decisions made. We also acknowledged the analyst's background and how it could influence the research process. Time was dedicated to each game according to its level of complexity. For example, games that presented a clear narrative progression were experienced or seen until the end, and complex strategy and simulation games were played and explored at length including a full reading of in-game encyclopedias, option menus and manuals, as well as use of forums and videos. In all cases, we triangulated our observations from the gameplay with other sources. In addition, notes were updated multiple times during the analysis and writing process for cohesiveness.

Although we built the avatar identity types using a systematic type-building process, we did not aim to create a canonical and highly abstracted classification, but rather an empirically grounded one [94]. The resulting types are polythetic, meaning that the cases within each type are similar but not always exactly the same in their norms and goals. Divergences can be found within types—some **empowered individuals** and **authorities** have different goals to otherwise similar cases—but also commonalities between them—**climate selves**, **climate citizens** and **climate heroes** have largely comparable goals, although they differ in their means; **empowered individuals** combine citizen and specialized behaviors, thus having overlapping norms with other types; and **authorities** and **faction leaders** follow similar norms while diverging in their goals. Yet, our classification has prioritized a level of abstraction both practical and insightful.

The presence of edge cases and games presenting mixed identities has been resolved by considering their main perceived ethos. This has been the case in the **climate self** game *Mission 1.5* [124], where players can make decisions within a simulated world but the ultimate goal involves real-world political demands, or *Climate, Please!* [125], where a lobbyist can nudge people to change with their own hands, although this secondary activity does not contribute to the game goal and thinly extends the norm-enforcing role. Some games, especially in the strategy genre, present multiple game modes with different ultimate goals and norms, but in these cases we have analyzed only specific scenarios focused on climate action. It is important to restate that these are types of avatar identity, not of game, so we encourage future games to mix different identity roles in single or multiple avatars in novel and interesting ways beyond what games usually present [154].

By adopting an ample understanding of what games are, using the lens of gamification, we have been able to provide a type of avatar identity, **climate selves**, not typically found in traditional games, where action is exclusive to the virtual world. Although there is no reason that games would not be able to mix in-game actions with real-world ones, as seen in, e.g., *Mission 1.5* [124], the concept of real-world behavior seems naturally associated with gamification. A study of other game and play forms, from live-action role-playing to gambling to toys, may result in other relevant phenomena emerging. However, given our focus on role identities enacting climate action given particular norms and goals, we assume that the conclusions of this analysis would be largely applicable to, e.g., most analog games.

This study has used content analysis as the method of inquiry. Therefore, it has focused on games and surrounding texts, rather than players themselves, to examine concepts such as avatar identities and climate actions and hypothesize about their potential for engagement. Disentangling the ways in which avatar identities can be realized in gameplay and interact with the players' selves requires examining a relationship involving actual players beyond an implied one. Future studies can use the relevant aspects presented in the results and discussion to explore empirically how that potential can be realized or contested.

Finally, the tendency of smaller games to disappear from the internet, and of popular games to be regularly updated, must be acknowledged. An example of this is Adobe Flash Player's end of life [5], which may have rendered some of the games analyzed here inaccessible after December 2020.

6 CONCLUSIONS

This article presented a qualitative text analysis of 80 video games where players explicitly engage in climate change mitigation and adaptation. We first sought to understand what identities could be found in these games, classifying our findings in six groups—**climate selves**, **climate citizens**, **climate heroes**, **empowered individuals**, **authorities**, and **faction leaders**. The potential of these avatar identity types for climate change engagement and avatar representation aspects were discussed.

Second, we focused on climate issues and actions to address them, observing that adaptation is often left for decision-making profiles, while mitigation actions are numerous in all six groups but addressed using different tools. We recommend climate actions such as policy, violence, technology, and nature-based solutions for future close study. More broadly, we encourage developers to address uncommon identities, i.e., **climate citizens** and **empowered individuals**, more often.

Third, we examined climate issues and their relationship to ultimate goals. We observed a tendency to have a single climate-related goal in games with **climate selves**, **climate citizens**, and **climate heroes**, contrasting with the more complex conflicting goals in other games. Building on recent research, researchers and developers should consider that enforcing pro-environmental behavior in games may not be necessary to support climate change engagement.

In sum, our study provided a basis for future researchers to study and compare how players experience climate identities and their climate change engagement effects. We also interpreted our findings in light of previous avatar-related work. We highlighted key aspects for developers to consider, as well as games for educators to select depending on their needs. Given the environmental impact of digital games, we call for research that explores climate identity in analog games, and encourage developers to critically assess the advantages of digital games while minimizing their negative impacts.

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PUBLICATION III

The good, the bad, and the divergent in game-based learning: Player experiences of a serious game for climate change engagement

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The Good, the Bad, and the Divergent in Game-based Learning: Player Experiences of a Serious Game for Climate Change Engagement

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ABSTRACT

Engaging citizens with climate change is an urgent and complex issue. Gamified initiatives such as game-based learning are used to promote awareness, emotional connection, and action, but we would benefit from more examples of how players truly play serious games and learn through them, especially regarding climate change, which presents unique characteristics as a learning topic. Thus, we developed a digital game about climate change and pandemics and thematically analyzed 12 players' experiences with it, including their relationship with the designed path, their possible deviations, and their engagement with the topic. Among our findings, we observe that progressing does not always involve interacting exactly as designed, and that game features that would be problematic otherwise can be accepted in the context of education. We also found that players may resist engaging in morally controversial in-game actions, give up in advance, or progress without understanding their actions' meaning. They also take actions diverging from a purely learning-oriented purpose, such as talking to and trying to interact with characters. Furthermore, game-based climate change engagement is complex and transcends learning new information. The results imply that game-based learning experiences cannot be completely guided, but designers are encouraged to clarify instructions to avoid moments of confused progress. In addition, players can frame educational games as different from entertainment ones in, e.g., their acceptable text amount, but not necessarily in terms of playful affordances. Accessibility and transparency should be addressed too. Importantly, the pedagogical and engaging value of adding playful interactions allowing for player autonomy, surprise, and character attachment should be considered. These can support player engagement and therefore maximize the educational value of games. Regarding climate change, we provide cognitive, affective and behavioral implications, including a call for designs that consider player agency and context.

CCS CONCEPTS

• **Applied computing → Interactive learning environments**; **Computer games**; • **Human-centered computing → User studies**.

KEYWORDS

game-based learning, serious games, gamification, player experience, climate change engagement, sustainability

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1 INTRODUCTION

Gamification, or the intentional transformation of activities and systems to afford game-like experiences [21], has permeated for over a decade multiple areas of society, predominantly education and health [26]. Game-based learning, a form of educational gamification, involves activities where players are expected to attain learning outcomes through game play [38].

One domain in which gamification has grown during the last decade is climate change engagement, where games have been explored and often shown to be successful in cognitively, affectively, and behaviorally connecting diverse players with the issue [17].

Dozens of computer games about climate change exist, and most of them are designed with the purpose to engage players with the topic [13] through multiple identities and actions [14]. However, multiple gaps have been identified in existing interventions both in researching the issue and in the games' design [17]. One game design challenge is to provide experiences that elicit effective user engagement with the topic on all levels, namely cognitive, affective, and behavioral [39]. Therefore, we created a digital game to research how game design can engage players, and how they react to the game's design. Informed by the literature on games for climate change engagement [13, 14, 17], the game includes features such as a focus on health as a climate change impact, a complex view of the citizen as an actor beyond consumer behavior, and prompting real-world player action.

Next, we conducted a study to explore how players truly engage with serious games and how they experience game elements introduced to elicit engagement. This is because gamification aims to engage players with a real-world topic and pursues outcomes, such as education or attitude and behavior change, but players may have other interests besides being persuaded. While some gamification typologies acknowledge that players motivated by change and disruption exist [49], serious game design frameworks focus on crafting experiences that support pedagogical goals but require players to behave as designers expect. This is potentially problematic, and not only given the importance of intrinsic motivation for learning [26, 38] and autonomy for enjoyment and effectiveness [11, 23]. If gamification design and analysis remain ignorant of gameplay events that do not strictly follow the designed path, such as acting before reading, greeting a character, mocking an element in the environment, or problematizing the game's content, these occurrences may counteract the designers' intentions. For this reason, our study aims to holistically answer the following research question: *How do players experience and interact with a serious game about climate change, including their relationship with the designed path, their possible deviations, and their engagement with the topic?*

2 BACKGROUND

2.1 Games and gamification

Although multitude of game definitions have been proposed [44], one of the most common used in games scholarship is Salen Tekinbaş and Zimmerman's "system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome." [46, p. 81]. Gamification, which can be used as an umbrella term encompassing concepts such as serious games and game-based learning [21], often uses principles of game design to transform activities so that they result in game-like experiences that support behavioral and cognitive changes [21]. Hence, intentional gamification shares techniques and principles with the discipline of game design, but departs from it by commonly seeking a utilitarian result beyond entertainment. In particular, game-based learning consists of using games, not always digital [38] and not always designed for educational purposes [37], to engage players in learning activities where an educational topic is not treated as content to be delivered but rather as part of a game system (i.e., an artificial conflict with rules and outcomes) that players engage with through a role and enacted (consequential) choices [37].

Broadly speaking, a game designer's role is to author a gameplay experience that hooks the player [16]. This is typically expressed as attempting to keep the player in a state of flow through a balance of challenge and ability [16]. In simple terms, then, a priority of game designers is to maximize moments of continuity, where players are actively using their skills to overcome challenging activities, and minimize discontinuity, or moments in which disruptions of this balance may make players bored or frustrated.

Gamification designers must commonly add the attainment of behavioral or cognitive outcomes to the provision of a satisfactory gameplay experience [21]. For this reason, they will typically focus on indicators, such as player engagement with the topic, that general methods of game design evaluation will not cover. Hence, specific frameworks exist to support serious games and game-based learning design. While the elements and categories considered vary among proponents (e.g., [2, 42]), a common assumption is that the player experience should be meticulously crafted [36], including their emotions [4] and forms of enjoyment [9]. In formal education particularly, curriculum demands may significantly shape the game content and structure (see, e.g., [22]). Where design frameworks have been proposed to be used as analytical tools, their goal is to understand how game design elements promote learning [5, 6, 8] or, more broadly, "productive" engagement with the topic. In summary, methodologies aimed at supporting game-based learning design focus primarily on how learning occurs, leaving out of the picture other aspects of the player experience.

More broadly, gamified systems aim to change behaviors and cognition, so they will work at their best when players are receptive to their messages; in other words, their implied player [1] is one who collaborates in being persuaded by the game and its message. However, players may want and attempt to engage with them in unexpected, messy, divergent and essentially playful ways. After all, games and play are becoming central and even ubiquitous in modern societies [21], so many players are used to freely play within structures fundamentally similar to those of serious games (e.g., digital commercial games for entertainment). Given that activities framed as games tend to prompt playful behaviors [11], it is only expected that players will want to do more than just play to learn exactly in the intended way. In this way, a tension exists between the educational frame and the play frame, and more specifically, between the designer's goal and the player's.

The fact that serious game play is often prompted by authorities such as teachers and employers, rather than the players themselves, may lead to issues. Forceful play can reduce the sense of autonomy and enjoyment and harm effectiveness [23]. However, if game play fits what players spontaneously feel inclined to do, or simply turn out to be enjoyable, these negative effects may be countered [12].

2.2 Supporting gamified autonomous learning

Given the importance of supporting player autonomy, multiple proposals of how to design for it have been offered. Even outside of games, designers have proposed encouraging free creation and communication, and using ambiguous design to support the user's autonomous meaning-making [18]. In game design, the core of the gameplay experience has been defined as making meaningful choices [46]. Choices may be meaningful, for example, given the possibility of failure, which in game-based learning may even be an integral part of the learning experience [38]. In this way, having the freedom to fail is not understood as a form of discontinuity, but rather as designed and expected. Other proposals to support player agency in game-based learning include promoting player freedom, e.g., via systems that permit exploration and system restructuring, and accommodating multiple play styles and approaches to problems [10]. In gamification, this would include those users who are motivated by change and disruption of the designed experience [49]. A broad reading of how designers direct freedom in games includes four types of limits: the possible (what can be done but is not necessary), the impossible (what cannot be done), the mandatory (what must be done), and the forbidden (what can be done but has negative consequences) [33]. Therefore, managing freedom includes not only imperatives, but also possibilities and discouragement. Players with a mental model of video games including these affordances will likely expect them in the context of gamification too, as occurs in design interaction broadly [35].

In fact, player agency goes beyond openness or meaning "by design." Especially in narrative games, agency need not involve choice, but a commitment to meaning in an interaction, that is, expressing intent and it being positively received [45]. More broadly, eudaimonic agency would not be only about affecting the game's system or narrative, but also interpreting one's own actions and reflecting upon the game's fictional elements [7]. A concept from the field of education relevant to game-based learning, agentic engagement, is defined as learners' "constructive contribution into the flow of the instruction they receive" [40, p. 258]. Agentic engagement is about personalizing the learning activity, making it more enjoyable and relevant to oneself, bringing new perspectives and asking for more content, among other things [40]. These perspectives shift the initiative and creativity from the designer-instructor to the player-learner. Indeed, it has been suggested that gamification should move away from a focus on the artifact towards a focus on experiences supporting eudaimonia, or a good life [11], and from extrinsically motivating mechanisms to enjoyable experiences of play as the core of game-based learning [43]. Designers have been encouraged to provide open spaces where players may find their own path, rather than determining a solution for players to discover [47], i.e., enabling rather than controlling [48]. These recommendations fit well with the characteristics of climate change as an engagement problem, described next.

2.3 Gamified climate change engagement

Beyond the general issues mentioned above, specific principles should be taken into account when attempting to engage players with a topic such as climate change. Unlike other challenges, climate change has been termed a wicked problem: it is physically and socially complex, large-scale, long-term, and solutions cannot be single, definitive, and satisfactory to the diversity of actors involved [25]. Furthermore, others have termed it a "super wicked" problem given that time is of the essence, those with the most power to address it also cause it, action is irrationally delayed, and its reach is larger than the legal and institutional frameworks in place [28]. Climate change is publicly discussed and players are likely to have some knowledge and opinion about it. In fact, public engagement with climate change can be seen as broader than scientific understanding: the engaged person will manifest a cognitive, and affective, and a behavioral connection to the issue [30], which complicates both the idea of the learner as a blank slate who either knows or does not know, and that of the serious game as a simple transmitter of knowledge.

While cognition, emotion and behavior have been long recognized as relevant components of student engagement [15], these are further complicated when learning about and/or gamifying climate change, given the complex psychosocial factors affecting climate change engagement [19, 34, 52]. Given the difficulty to promote deep and lasting engagement with climate change, experts have proposed replacing top-down approaches, which assume that the main issue is a deficit of information, with dialogic strategies that consider the public's personal circumstances [53]. In this vein, methods promoting interactivity and engagement have been deemed effective [32, 39].

In particular, gamification has been found to be effective across the climate change engagement spectrum while providing enjoyable and meaningful gameplay experiences, but challenges and gaps still exist and need to be studied [17]. This is not limited to intentional gamification; both games for entertainment and serious games show climate change engagement potential according to expert criteria [13]. In addition, games have been found to provide a diversity of identities for players to embody and explore [14] which is positive given the multiplicity of actors involved in climate change action and the need to rethink and expand the role of citizens in it [53]. The game used in this study was designed to provide information about a largely unknown topic, the connections between climate change and infectious diseases [51], but switches to an emergent dialog model when considering climate action [3]. Thus, despite its didactic structure, where interaction largely supports information, the game applies at various times guidelines proposed for emergent dialog in games [3], e.g., showing causes and consequences rather than right and wrong; providing mechanisms to support discussion about content; and allowing players to autonomously set their own goals. This dialogic approach is in line with agentic engagement [40] and, while limited by various constraints, it aims to merge traditional, teaching-like experiences with more player-driven ones. The game is described in detail next.

3 METHODS

To answer our research question, we conducted an exploratory study to observe how players experience the game, including their relationship with the designed path and the possible deviations from it, and their engagement with the topic. For the study, we recruited 12 participants who played the game to completion. Qualitative data was collected in the form of observational notes and interview responses. Thematic analysis has been used to analyze the collected data. Next, we describe three methodological perspectives of the study: a description of the game system used, the data collection context, and the data analysis process.

3.1 Game system description

This study employs a serious game for climate change engagement, *Climate Connected: Outbreak*. The game has been designed and developed by the first author. Similar versions of the game exist for VR systems and regular computer screens. The game is designed to be played and completed in a single session of one hour or less.

The game discusses the topic of pandemics and other health issues that can be worsened by degrading environmental conditions. Its central message is that environmental, animal and human health are interlinked, and that climate change worsens all of them [50]. In this way, the game connects climate change with quotidian issues and propose action at the root of the problem (i.e., greenhouse gas emissions reduction). The game presents a linear narrative where players solve riddles, find objects, complete minigames, and answer questions.

In the game, the player travels to the year 2050. The game story is structured into **four chapters** (see Figure 1 for details). In the **first chapter**, the player is presented with an optimistic version of the future, which is soon substituted by a more likely one where the world is living a global pandemic as the environmental situation continues to degrade. Soon, the player is acquainted with a spirit of nature who invites them to explore the connections between climate change and the pandemic through day-to-day objects that can be found in their virtual apartment.

In the **second chapter**, a basic game loop repeats several times. First, the spirit of nature proposes a riddle pointing to an object representing an element of the climate-health system. Once the player finds it, they must complete a minigame. The game has 14 different objects to find (two in the first chapter and 12 in the second one), each one with its corresponding minigame featuring a unique mechanic and goal (e.g., extinguishing a wildfire or switching a console to renewable energy). With each new object found and minigame completed, a conceptual flowchart grows progressively from impacts to causes of climate change.

The **third chapter** starts once the flowchart is complete. In it, the spirit of nature quizzes the player about topics ranging from the causes of climate change to its various impacts for human and ecosystem health. Thus, the inverse path is followed, this time from causes to consequences.

The **fourth chapter** introduces climate action as a deeper way of facing pandemics given that it can prevent them by acting on their root causes. Players are asked about how they feel about the topic (e.g., alarmed, concerned, unsure, skeptic), and the game provides feedback based on their responses. Motivation and amotivation are addressed, as well as additional pedagogy and acknowledgment of personal and environmental barriers to action. Then, they are invited to commit to one climate action. If they agree, they are proposed different possibilities, including acquiring more knowledge, individual and collective action, and artistic creation related to environmental issues. Once they select a general category, they are sent an email with more specific actions that they may take.

In this way, the game is a combination of a top-down approach aiming to educate players, given the apparent lack of public knowledge about the link between climate change and infectious diseases [51], and a bottom-up one, which is appropriate for climate change engagement given the ineffectiveness of prescribing actions instead of taking into account the player's situation and preferences. In general, the health implications of climate change are rarely addressed in previous gamification studies [17].

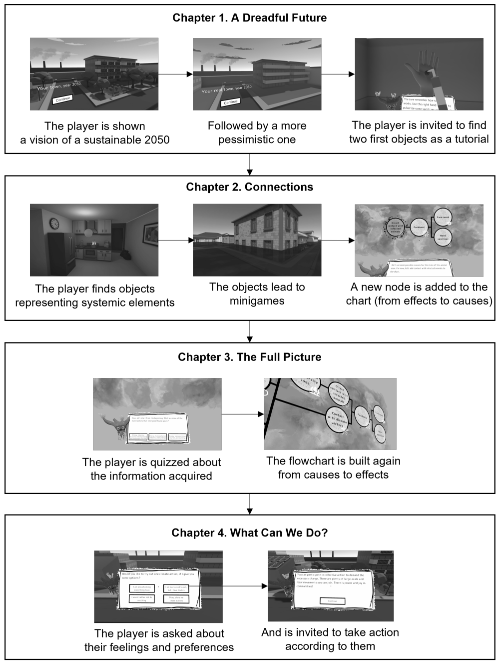

Figure 1: The game's structure.

In this study we used a beta version of the game where some aspects were provisional. For example, it featured the intended colorful low-poly graphics but some objects did not have their final appearance. The game included various sound effects, but not music. Elements such as graphics and audio can have an effect on engagement and immersion, and can facilitate comprehension of the content and gameplay. Nonetheless, the informational content and structure of the game were almost final. From the design and development perspective, this study covers one iteration of the game design according to the user centered design process [20].

3.2 Data collection

For the data collection, we conducted individual tests in a computer with 12 players (6 female, 5 male, 1 did not say). The participants were recruited through an open call for volunteers sent to the local network of the authors who collected the data, chiefly from their academic environment, irrespective of study subject. Players had different degrees of self-assessed video gaming experience and environmental knowledge, resulting in four groups of three participants according to their combined gaming experience (high/low) and environmental knowledge (high/low). The selection of a diverse sample aims to support the findings' generalization. The ages of 11 participants (one preferred not to say) were between 20 and 35, with a median of 24.

The average completion time was 47 minutes (min. 32, max. 64). Although the game was played from start to end, the participants of this study did not receive an email with specific climate actions at the end of their gameplay. They did have the choice to select a general category of action that they were interested in pursuing, but the follow-up email was not part of this study as we were interested in how players experience the game in situ.

Data were collected during April of 2022. Each data collection session followed the same procedure. Participants declared their experience with games and knowledge of environmental issues as high or low; read the information sheet and data privacy statement and signed the informed consent; completed a climate change concept map; played and completed the game; and revised their concept map. During gameplay, authors 2 and 3 took written notes of players' actions and comments. After playing, the researchers also interviewed the participants regarding usability (issues, discomfort), playability (enjoyment, dislikes, improvements), and engagement with the game and climate change, including cognitive (learning), emotional (feelings during play), and behavioral (effect on their view of their own life and actions). In this paper, the analyzed data consists of observational notes of gameplay and interview answers. As recommended [41], we use multiple data sources to support the study's validity.

3.3 Data analysis

To analyze the data, we followed a thematic analysis process [41]. consisting of two phases: (a) data management and (b) data abstraction and interpretation [41]. The first step in data management is familiarization. Here, authors 1, 5, and 6 read the data and independently listed subjects of interest relevant to our research question.

The second step, constructing an initial thematic framework, comprises the creation of themes and subthemes to organize the data. In this step, the three researchers created between 5 and 7 themes linking particular items, with as many subthemes as needed, based on the data. Next, the researchers met and created a common framework, which would be used to tag the data, every theme and subtheme being a code. The framework consisted of six themes: (1) continuity, or forms of progress according to the game's design; (2) discontinuity, or moments where advancement is frustrated; (3) divergence, or events where players depart from the intended path without causing discontinuity, that is, without blocking progress; (4) topic engagement, or events where players engage (or not) with climate-related topics; (5) representation and mediation, including ways in which players engage with core elements of the game; and (6) emotions, or moments where players showed or described a particular feeling.

For the third step, indexing and sorting the data, we used ATLAS.ti. This step consisted of annotating the data according to their belonging to the themes and subthemes proposed. The three researchers tagged in this manner the data from two participants and met to compare their notes. The involvement of various analysts aims to support validity through triangulation [41]. After various limitations were pointed out, some subthemes were slightly modified and/or clarified and two researchers proceeded to independently code all the data. Then, following a process of consensual coding ([24], cited in [27]), the two researchers met and discussed until a consensus was reached for all chunks of data.

In the fourth step, reviewing data extracts, one researcher used ATLAS.ti to re-read the data once again, this time according to their labels. This step was done closely with the fifth step, data summary and display, where a spreadsheet was created for each theme containing all of its associated data, with the subthemes as columns and the participants as rows. During this time, the data was refined further and the two last themes were reorganized as subthemes.

After the data management phase, abstraction and interpretation steps were undertaken. This involved using spreadsheets and text documents. First, the same researcher who summarized the data developed categories from it. These categories aim to capture the range of ways in which a theme or subtheme manifests. This process included finding elements, or distinct types of response, in the themes and subthemes. Next, they were sorted according to key dimensions of the players' experience and behavior, and finally these dimensions formed more abstract categories. The aim of categories is to label the data in a more interpretive way so that the research question can be addressed through a more meaningful understanding of data and the phenomena that it points towards [41]. Finally, we report some links among the data and explanations for phenomena, mainly in the form of explicit reasons given by participants.

4 RESULTS

The data analysis resulted in four large themes (continuity, discontinuity, divergence, and topic engagement) that also constituted the thematic framework for identifying and grouping lower-level subthemes and categories. The continuity theme includes aspects in the game experience that indicate that the player proceeds according to the game design. Discontinuity refers to moments when the advancement is interrupted or frustrated. Divergence refers to events and behavior that departs from the intended path, but without causing discontinuity. Finally, topic engagement consists of indications that players engage with climate change and how it is represented in-game. The themes also include aspects related to other two themes initially present, namely representation and mediation and emotion, which have been incorporated according to their fitness (e.g., representation elements that favor continuity; emotions felt in relation to discontinuity). For each theme, various subthemes were identified (shown in bold below), 15 in total, representing relevant aspects of each theme. Furthermore, multiple categories (in italics below), 43 in total, summarize and abstract how particular subthemes (bolded) occurred in the data, pointing at particular player behaviors, emotions and cognition. For a summary of all themes, subthemes and categories, see Table 1.

4.1 Continuity

The continuity theme includes four subthemes and 10 categories. The first subtheme is **goal preparation**, which describes the actions performed before achieving a goal. Three categories of actions were observed in this subtheme. First, players prepared for their goals by *reading instructions*, which occurred primarily when facing a new situation, task, or challenge, and as a means to recover

Table 1: Results of the thematic analysis, including themes, subthemes, and categories

Theme	Subtheme	Categories
Continuity	Goal preparation	Reading instructions; Methodical exploration; Reasoned or clearly prompted exploration
	Goal attainment	Purposeful but spontaneous goal attainment; Purposeful and reflective goal attainment; Excess in goal attainment
	Design-enabled player failure	Failure due to lack of attention; Failure due to lack of knowledge
	Evaluations and emotions supporting continuity	Evaluations of representation contributing to continuity; Emotional continuity
Discontinuity	Limited goal preparation	Lack of visual guidance; Lack of textual guidance; Missing information with a negative experience impact; Missing information with no serious consequence; Aimless exploration after lacking information; Aimless exploration despite a reasoned or clearly prompted task; Aimless exploration that gets resolved by chance
	Goal-related discontinuities	Failed premature goal-directed action; Unsupported goal-directed action; Accidental or thoughtless goal achievement
	Unintended failure	Technical failures; Anticipating failure
	Psychological and physical resistance	Resistance to engage; Player limitations affecting game reception
	Evaluations and emotions related to discontinuity	Evaluations of representation contributing to discontinuity; Emotional discontinuity
Divergence	Divergent behavior	Divergence with creatures and characters; Environmental divergence; Failing on purpose to see the consequences
	Humorous comments	Humorous comments about the environment; Humorous comments about creatures and characters; Humorous comments about information
Topic engagement	Engaging with new information	Learning; Doubts and misunderstandings
	Connecting information to the past and future	Limited learning; Knowledge of oneself and one's action; Knowledge and perception of the world; Effect on intention and future ideas; No change in intention
	Teaching the game	Criticism of the content; Criticism of the medium
	Topic-related evaluations and emotions	Evaluations of representation strengthening topic engagement; Emotional topic engagement

from failure or being stuck. Second, players engaged in *methodical exploration* by looking and moving around, which would typically end with finding the right object, whether by intention or chance. The data depict ambiguous moments when it is not clear whether the player is exploring in search of something they have an approximate idea about, or just aimlessly drifting. As the gameplay data is based on observation, we had to rely on behavioral cues. Thus, we considered the absence of clicking as methodical exploration due to players abstaining from taking the action that signals identification (i.e., clicking an object) until they are reasonably sure. Third, players prepared to achieve the goal via *reasoned or clearly prompted exploration* by looking for an explicitly described element or engaging in actions to support their search. Players explored the environment under correct premises, for example expressing a reasoning or reading or recalling past findings, or incorrect ones, for example based on wrong expectations (e.g., expecting to see a rat after a clue refers to "smaller animals") or searching in the wrong place (e.g., looking for an object within a virtual screen instead of the 3D environment). Even if guessing under correct premises, it was possible to fail because the game did not support their action, which is a form of discontinuity that will be explained in section 4.2.

The second subtheme is **goal attainment**, which describes how goals were attained in ways that supported continuity. Three categories were observed. First, players engaged in *purposeful but spontaneous goal attainment* by achieving the goal without careful thought. This is the case with tasks that were simple and repetitive, therefore they could be completed via experimentation (e.g., applying sanitizer and rubbing hands together), or through casual exploration (e.g., finding mosquito breeding grounds in a small environment). Second, players engaged in *purposeful and reflective goal attainment*, which is directly connected to the forms of goal preparation above. This included times in which they succeeded after reading attentively task instructions and information, but also after failing and seriously reconsidering the information. This form of goal attainment also followed discontinuity, e.g., lack of game responsiveness when similar attempts did not work (e.g., the player is selecting an object that makes sense but is not the one that the game wants) or after a very different action did not yield any result (e.g., watering a tree before seeing that the top is on fire). Interestingly, players also engaged with purposeful goal attainment that had a personal meaning, which was observed during gameplay via explicit comments (e.g., "I hate mosquitoes") or uttered emotional exclamations (e.g., "Nooo, not the trees!" or "Oh, my God!" as the sea level rises). Third, players enacted *excess in goal attainment* by repeating an action that could have been performed just once. This includes excessive clicking (e.g., putting out a wildfire) which was sometimes joined by an emotional comment ("Nooo, not the trees!") but may have been due to slow game feedback. Players also repeated entire processes, for example boxing multiple items in a single box when only one would have been enough, which may not have been clearly communicated by the game. Players occasionally went too far by engaging in unnecessary extra actions such as moving plants to dry land instead of just uprooting them. This may also be due to lack of guidance and feedback, but could indicate that players had the capacity and wished to solve more and harder challenges.

The third subtheme, **design-enabled player failure**, includes moments in which players fail in a way that is supported by the game. Two categories were identified: *failure due to lack of attention*, that is, not reading attentively, and *failure due to lack of knowledge*, especially when answering the quiz. In one case, this led to player frustration.

The fourth subtheme, **evaluations and emotions supporting continuity**, includes two categories. First, opinions and appraisals of game aspects such as the game's environment, characters, audiovisuals, information, options, controls, and mechanics-dynamics. These *representational aspects contributing to continuity* include players being amused or sad about characters (e.g., a dead bird), which left some players wanting more. We considered that liking the game's chart, finding the writing funny, or considering the amount of textual information as adequate supported continuity, as did liking the choices offered by the game. Players also manifested that they found the exploration fun, the game easy in a positive way or that they were stuck "but not for too long." Some evaluations were idiosyncratic of serious games or a testing session, for example one player manifesting that there was a large amount of text but that this was expected from an educational game or that the game lacks polish but it is "okay." Second, various forms of *emotional continuity* were observed, which we clustered around enjoyment-related continuity, including most of the elements described in the category above, and relief and relaxation-based continuity, for example relief when a new object is found after aimless exploration or feeling relaxed at the end of the game.

4.2 Discontinuity

The discontinuity theme includes five subthemes and 16 categories. The first subtheme is **limited goal preparation**, defining moments in which players face tasks with insufficient or inadequate means. This subtheme includes seven categories. Two similar ones are *lack of visual guidance* and *lack of textual guidance.* Lack of visual guidance occurs when a lack of visual elaboration renders interactions too abstract (e.g., the player is asked to put glue but has no glue in their hand) or when inconsistent animation leaves players confused about what is a relevant element and what is not (i.e., some objects are animated, some are static). It also happens when objects appear unremarkable but are in fact what the player should find, which may lead to players completing a segment of the game without having understood the meaning of their actions, and when objects are too hard to find. Textual guidance is lacking when instructions are unclear or cannot be reread, but also when many objects could reasonably be the solution but the game will only accept one (e.g., a console and a computer consume energy, but the right answer is one of them) or when the player chooses an option in the game expecting it to mean something different. Lack of guidance can result in aimless exploration, although players may add ambiguity to this by stating that "maybe [they] didn't read everything clearly," therefore suggesting a fault on their part.

A third form of limited preparation occurs as *the player misses information with a negative impact on their experience*, either being lost or taking unsuccessful actions, even needing to retry. Fourth, it may also be that *the player missed information but the game continues almost the same*, when the goal is obvious enough or when advancement is nonetheless permitted, e.g., skimming the text while answering a quiz.

The previous issues will often result in the fifth category, *aimless exploration originated in lack of information*, which may be ended sometimes by seeking more information (e.g., rereading). Sixth, the player may engage in *aimless exploration despite a reasoned or clearly prompted task*, for example when they explicitly recall their task but that is not enough to put them on the right track, or straightforward information is not enough (e.g., the instructions say that an object is to the player's right but they still look around, confused). This sometimes culminates in the seventh category of limited goal preparation, *aimless exploration that gets resolved by chance.* This includes processes which the note-takers deemed "random clicking," "clicking around," and "pixel hunting," or players aimlessly clicking everywhere when trying to find an object. Sometimes this aimless exploration leads to frustration, and sometimes the player vocalizes their issue (e.g., "I don't know what I'm searching for" or "there is too little information on what I'm looking for"). Typically, aimless exploration will result in an accidental goal attainment, described in the following subtheme.

Goal-related discontinuities include moments in which players interact with goals in ways that are not ideal from the design standpoint. This includes three categories. First, *failed premature goal-directed action*, when the player tries to complete a goal but is missing a previous step (e.g., trying to put a mosquito net before applying glue to the door frame). Second, *unsupported goal-directed action*, when players engage in a form of interaction or select an object that is unsupported or incorrect. Third, in other cases, *the goal is accidentally or thoughtlessly achieved*, which, despite moving the game forward, is a failure as the player does not advance consciously. For example, they may accidentally interact with the right element as part of aimless exploration or select an object without knowing what it is, especially if the visual guidance is limited. They may also achieve the goal having understood the required interaction but not its meaning. They may also experience a happy coincidence, when they find the right object purely because it is new or animated, or when a technical bug allows task completion in an unconventional manner, or even when the player selects an object "as a joke" and it surprisingly works.

The third discontinuity subtheme, **unintended failure**, includes both *technical failures*, which are common bugs such as a scene not loading or inconsistent collision detection, and *anticipating failure*, or players thinking that they will not be capable of recalling the provided information (i.e., "This is a very big chart, I don't know if I have to remember everything because I won't"). Meanwhile, the fourth subtheme, **psychological and physical resistance**, includes two categories where players refuse to act, rather than the game failing. In *resisting to engage*, players declare discomfort with a task due to, e.g., having to enact violence or cause environmental damage, even if the task is framed in the game as damaging. Resistance can also occur when *player limitations affect game reception*, either because the game makes them physically ill due to motion sickness or because they were already sick, which can result in tiredness.

Finally, the data shows **evaluations and emotions related to discontinuity**, including two categories. First *representational issues contributing to discontinuity*, for example the environment being visually confusing, the characters being not liked because of their personality or looks, the language containing difficult words (e.g., quotidian, pulverize), players wanting hints to mitigate discontinuities, excessive difficulty, unclear controls, and other issues mentioned above as part of other subthemes. Second, *emotional discontinuity*, with two clusters observed: anger and frustration-related discontinuity, and confusion and surprise-related discontinuity. Anger follows being stuck, while frustration derives from various features (e.g., throw sensitivity, aimless exploration, own failures, lack of options). Meanwhile, confusion and surprise occur during exploratory behavior or when providing an answer.

4.3 Divergence

The divergence theme includes two subthemes and six categories. The first subtheme is **divergent behavior**, or moments in which players took actions in the game that were not apparently aimed at progressing. Three categories were built here. First, *divergence with creatures and characters*, that is, trying to use a tool on a character. Players engaged in this way with the two main creatures in the game. This includes a cow, to which they threw water, possibly to prevent it from eating crops, and the game's guiding character, whom they tried to mask, spray with water, and shoot at. Some players expressed wanting more mechanics for character interaction, such as spraying water, which signals a will for the game to acknowledge their divergent behavior; in other words, divergent interaction. A second form of divergent behavior is *divergence with the environment*, or players trying to affect elements in the game unprompted and wishing for more interactions (i.e., "it's not the point of the game but I'd like to be able to spray the whole thing"). Sometimes these environment-directed actions were ambiguous, given that players may be trying to select environmental elements just because they want to advance in the game and don't know how to. Utterances such as "can I open things?" can be interpreted both as a desire to explore for exploration's sake or as asking for clarification when being goal-oriented. On other occasions, players may engage in non-prompted actions such as watering tree roots before noticing that their tops are on fire, but this may also be because they think that is what they should do to progress. Third, *failing on purpose to see the consequences* was also divergent behavior, e.g., waiting for a while before completing a task to see if something will happen, or choosing an incorrect answer because it sounds amusing.

The second subtheme, **humorous comments**, includes player utterances about the environment, characters, and the presented information. Three categories were formed. First, *humorous comments about the environment* consisted of comparisons between game elements and similar outside elements, such as a minigame looking "like CS:GO," plants looking "like weed," a planet covered in pollution looking "like the coronavirus," and a wooden toy looking "like its from a ritual." Other comments may have been also divergent, such as saying that "there is a lot of toilet paper" in the bathroom, but these were put already by design to express a humorous truth (people hoarding toilet paper during emergency situations such as pandemics). Second, players also expressed *humorous comments about creatures and characters*, including their appearance ("The character is cute but it's staring into my soul") and, ambiguously, about the avatar itself ("Where is my shadow?," "I have no feet?"). Players also interacted with characters by greeting them aloud when they first met them. Third, players made *humorous comments about information* given, including sarcasm and dark humor about the writing ("I would love to eat cardboard for sure") or the goal ("looking for a nice place to die"), and commenting on the options given (i.e., the game allows players to express that climate change is a lie, which one participant found funny).

4.4 Engagement with the topic

This theme includes four subthemes and 11 categories. The first subtheme, **engaging with new information**, includes two categories, the first of which is *learning*. Players learned connections that were previously unknown, especially the connection between climate change and pandemics, and that climate change is pervasive, including its causes but also individual and collective responsibility (e.g., "[the game] put things into a bigger perspective, we are a small piece in the whole ... individuals can do a lot but it's mostly about the bigger institutions"). They also learned new pieces of information, including causes (e.g., "There are greenhouse gases in the AC?"), mechanisms (e.g., the fact that a warmer ocean will expand and thus rise), impacts (sea level rise, animal well-being), solutions (reducing meat consumption, sustainable production of toys), and concepts (zoonosis). One emerging issue was that players could give too much importance to elements provided just as examples of larger sectors (e.g., toys for industrial production, video games for energy consumption) to the point that they would refer only to the example. Of course, engagement with new information may come with *doubts and misunderstandings*, either because an element's presence is unclear ("Why was a dead bird in my bathroom? It doesn't make sense!") or because the information given is misunderstood ("Not sure if the pandemic caused drastic climate change, or partially contributed to it").

The second subtheme reflects ways in which players were **connecting information to the past and future**. This is linked to five categories. First, *limited learning*, when players expressed that they already knew most of what was being shown in the game. Second, *knowledge of oneself and one's action* such as the participant's personal circumstances affected topic interpretation, including comments about barbecues in their country of residence not being sustainable, the fact that the participant is more climate-conscious at home than in their Erasmus, and one participant saying "I have contributed to this a lot recently" referring to flights. Players also expressed their personal preferences in connection to in-game topics ("I hate mosquitoes") and connected their present life to the future depicted in the game (e.g., the player "[feeling] sad because it's going to be bad in 30 years, will we be able to do things as we are doing them now?"). In addition, personal awareness and action may limit the game's influence. Participants stated that their behavior would not change because they were already aware of environmental problems and behaved in a responsible way, so the game could be seen as a reminder. Participants may have even tried to tell others about these topics, but found that their effort did not yield the expected result.

Third, players also connected the topic to their *knowledge and perception of the world*, which affected their expectations of the game (e.g., the player already expected the future to look grim). Existing environmental knowledge and perceptions resulted in players connecting game events with aspects not mentioned there, such as saying "poor Netherlands" when shown sea level rise, or even proposing their own solutions (e.g., "you can make food for cattle with insects, which produces fewer emissions"). Existing knowledge and perception of society were also relevant, with participants saying that "it's all around us but we don't care", or expressing disappointment or "frustration that we know it all but we still need things like [this game]."

Fourth, the game had an *effect on intention and future ideas*, either general (declaring that they will remember the game when "an opportunity to do things" arises) or more specific, including personal consumption (eating less meat, reducing airplane travel, buying less fast fashion, eating insects, taking shorter showers, not using plastic-packaged goods) or becoming more influential (i.e., "go into politics and try to be a good politician"). However, and as the fifth category, the game also resulted in *no change in intention*, sometimes due to lack of perceived new ideas (e.g., "I'm more educated but I don't know what to do with it"; "[The game is] informative but [provides] no suggestions on how to decrease the crisis"). Other reasons included psychological barriers, such as temporal distance ("it has not happened yet so [I am] just mainly ignoring it") and individual action being inconvenient.

The third subtheme, **teaching the game**, includes moments in which players criticized the content or the medium. First, *criticism of the content* were directed at depictions of wasted resources that the game did not acknowledge (i.e., boiling water wastes energy, the packaging in a minigame was excessive, and closing a door with water is a waste). Second, *criticism of the medium* refers to commenting on the game as a video game that tells players that video games are bad for the environment. While this may have been said with the intention to signal hypocrisy, this was not clear from the participant's comment.

The fourth subtheme, **topic-related evaluations and emotions**, contains two categories about player engagement with different elements in the game and expressed or observed emotions. First, *representational aspects strengthening topic engagement* were found, specifically in the environment and the information. Environmental topic engagement included, e.g., expectations of the future prompted by the game's environment and care for sea level rise, as well as emotions such as worry, surprise, confusion, and sadness. Information-based topic engagement included the game showing consequences in a way that "increases concern," but also the opposite: one participant stated that the information is not emotional enough ("giving information just to read will not change my outlook on life, it would be better if there would be some stronger turning points ... if the information was more emotional then it would be better"). This leads to the second category, *emotional topic engagement*, which was clustered around three ideas. First, frustration and disappointment because of lack of real-world action, which is a form of engagement but may become apathy. Second, sadness, concern, and overwhelm when considering the consequences of climate change and the future, including negative feelings prompted by enacting unsustainable behaviors in the game as part of the gameplay. Third, surprise and curiosity from information and environments shown in the game, including utterances such as "Oh my God!" and "that is too much" when shown future sea level rise.

5 DISCUSSION

In this study, we have devised a thematic analysis framework to show ways in which players engage with a serious game and its topic. Answering our research question, *How do players experience and interact with a serious game about climate change, including their relationship with the designed path, their possible deviations, and their engagement with the topic?*, we have uncovered various ways in which continuity, discontinuity, divergence and topic engagement occur. While existing frameworks tend to focus on game elements supporting learning, we extended our observations beyond such elements to focus on players' behavior, experiences and engagement as observed during the gameplay and based on after-game impressions and reflections. These were later organized into subthemes and categories. This approach allowed us to show the nuance of game elements' effects; for example, a particular beat of the game such as exploration can lead to continuity and desired topic engagement once, but may lead to discontinuity and confusion at a later time, or with a different player. Because game mechanics and features are complex, interact with multiple other elements, and underpin different moments in games, nuanced and varied interactions are likely to occur.

The designer's goal is to author a desired player experience [16], which we call here facilitating continuity. In game-based learning, this is no different [36]. In our study, we found that continuity was supported in multiple ways. In behavioral terms, some actions advanced the game, but players wasted effort in unnecessary repetition due to misunderstandings. Sometimes, design-enabled failure occurred, but in this game it was not due to lack of a particular skill, but rather because instructions were ignored or misread or players failed to remember a given fact. This form of continuity-related failure often prompted players to do better the second time around, which is different from the feeling of discontinuity that follows a design's fault. However, some potentially problematic game characteristics were accepted in the context of it being a serious game for research, used in a test session, rather than a game for entertainment or one that is commercially available, namely the large amount of text and the lack of polish. This suggests that players see serious games as learning experiences, and thus educational features like long texts to read are often expected and accepted as such. This is a promising finding as it has been previously observed that students prefer learning about climate change through games over other instruction methods [17].

This study found forms of discontinuity that are rarely considered in gamification scholarship, such as players' resistance to play for moral reasons or the impact that illness and physical discomfort can have in the gameplay experience. We also found that players may anticipate their own failure if they start to feel overwhelmed by the content, even if the intention of the designer is not total recall. In a similar vein, it was pointed out that complicated words stop the flow. Using everyday language rather than technicalities will usually provide a net benefit [31]. But most importantly, it was observed that players may advance without understanding the meaning behind their actions. This is crucial because forms of gameplay such as procedural rhetoric [3] rely on interaction to convey meaning; designers may want to reinforce such core ideas to make sure that they are understood, as game progress does not automatically imply learning [29]. Finally, ambiguities were observed once again, this time between what constitutes genuine lack of guidance, and what is lack of attention by the player.

This study also uncovered ways in which the experience is not, and cannot be, completely designed and guided, especially in terms of divergence and topic engagement. Our divergence-related findings support the idea that players wanted to do more than learn in the game. They did not only engage in actions that were not directly designed nor were obviously aimed at learning the content, but they explicitly communicated a want for more divergent interaction, that is, a desire to horse around and engage in free-spirited exploration [49]. Of course, the context of the study mattered, since the participants were personally recruited by the researchers present in the testing, which may have prompted them to be relaxed and playful. However, the same may occur in any other context, for example when students are in class surrounded by friends, or even alone at home. Although the well-known player divergent behavior of attempting to break the game and disrupt the system [49] was not observed, it does occur and designers should take it into account.

Finally, the pedagogical aspect of the game did not always have the expected impact. Climate change engagement involves cognition, affect, and behavior [30]. In cognitive terms, the game did show new connections to players, but the basic aspects of climate change were generally well-known. Thus, players engaged with the information in their own terms, and it was difficult to surprise them or even teach them something new. Interestingly, players sometimes reached conclusions that were not prompted by the game, making use of their previous ideas. A clear example was a participant who proposed eating insects as a less carbon-intensive dietary option. Furthermore, players may even teach the game when they see something that counters the pro-environmental message. Like moral choices, players may take these seriously even in a fictional frame. These examples and divergent behavior in the game can be associated with agentic engagement with the game and topic (see [40]). Conversely, designers should be careful with the examples that they set for larger issues, since players can assume that these have been chosen because they are the most relevant ones.

In affective terms, complex emotional relationships with the topic were observed. Players did not only relate to events in the game both positively and negatively, but they talked about their feelings towards the topic and how playing the game had reminded them of the state of the present. Even through a serious game, the complex emotional dimension of engagement [19, 34, 52] were experienced and discussed.

As previously outlined [3, 52], the didactic approach was limited in supporting behavior change. Participants often claimed to already do things for the environment and complained that the game did not give them new ideas. While this aspect will be reinforced in future iterations of the game, various actions were already communicated throughout the game. This suggests that even if designers think that clear action is suggested, players may not view it as such unless it is explicit and personalized. This game tackled the challenge to communicate a topic that players generally know about (climate change) in a new way (its connections with pandemics), but this new angle will not necessarily spur players to act. At this point, a priority should be made of identifying the main factors preventing the necessary scale of climate action, the role of citizens in it, and how games can support them while providing holistic opportunities for engagement and respecting player autonomy.

In summary, our method of inquiry and its results extend existing game-based learning frameworks in two general directions. First, beyond design. While frameworks advocate for a meticulous craft of the player's experience [36], including their emotions [4] and enjoyment [9], we observed ways in which designers cannot anticipate and adapt to every player's thought, feeling, action, and personal baggage. A telling example is the difference between designers' understanding of enjoyment as flow [9, 16] and players' self-directed exploration and humor. This should be examined further in terms of learning impact, since unexpected learner contributions can lead to pedagogically valuable moments [40], perhaps even for game-based learning designers. Thus, we propose to complement design prescription [2] and the study of intra-design tensions [42] with further experience description and design-experience tensions.

Second, beyond learning. While analytical frameworks aim to understand the relationship between design elements and learning [5, 6, 8], our observations yielded not only surprising examples of continuity, but also highlight the value of looking beyond "productive" motivation, engagement, and learning. Furthermore, we focused our observations on climate change to study what game-based learning looks like for such a complex topic. In a further expansion of learning, we inquired about the game's implications in the learner's life beyond "performance improvement."

5.1 Limitations and future research

This article has aimed to support the study's reliability by communicating with transparency and detail the processes followed, data collected, and analysis made. Two data sources and direct examples were used to strengthen measurement validity, rigorous data collection and analysis processes were followed to support internal validity, and a diverse sample was sought for external validity. However, the study presents limitations that should be mitigated in future studies. First, the sample, although adequate in number for a qualitative study and varied in terms of self-declared game expertise and environmental knowledge, was contextually homogeneous, since participants were recruited around the same university. Future studies should explore how different players interact with gamification in other contexts.

Similarly, this study has used a particular game with characteristics that not all serious games will share: a linear, narrative experience lasting under an hour and focusing on climate change. While some of the findings from this study may be found in other serious games, others may be specific, such as the forms of continuity based on exploration and finding objects. In addition, the players were not exposed to the last step of the game experience, where they receive an email suggesting specific climate actions. Future studies with this game should focus on evaluating the complete experience, especially given player comments that it did not provide new ideas; observe longer term effects [17]; and compare game versions to understand the impact of, e.g., introducing more opportunities for divergence.

Future studies are encouraged to use the basic concepts of continuity, discontinuity, divergence and topic engagement to examine the relationship between players and serious games, and more broadly to update their implied player [1] to one who expects a more open management of their freedom [33]. They may also choose to focus in more detail on a particular theme of interest and probe participants about the reasons behind their comments and actions, especially the more ambiguous ones, while asking what players think of particularly unusual forms of divergence and topic engagement. For example, the gameplay notes analyzed here contained ambiguous data that we could not be sure to interpret correctly. In the future, this data may be triangulated with sources such as video, psychophysiological measurements or questioning about interesting or unclear events, although this would increase the data to analyze.

6 CONCLUSION

The urgency and complexity of climate change have led to the use of gamified initiatives aiming to engage players with it. However, the ways in which players truly play serious games and learn through them deserves scrutiny with real examples. We developed a digital game about climate change and pandemics and took notes from the experiences of 12 players with it. Then, we explored the data using a qualitative thematic analysis method, which reveals the multiple ways in which players enact continuity, endure discontinuity, express divergence, and engage with the topic. To promote continuity, designers should clarify what is expected of players and be aware that quirks and imperfections may be expected and forgiven due to expectations of educational games. To reduce discontinuity, designers should consider the accessibility issues that may arise from their games, and try to make interactions and metaphors as transparent as possible if they are supposed to convey a single meaning. The findings also include players enacting, and expressing a desire of, divergence. Designers should consider and further study the pedagogical and engaging value of adding playful interactions that support player autonomy, surprise, and character attachment. This can support player engagement and thus increase the educational value of games. Finally, it was observed that players engage with the topical content in complex ways beyond assimilating new information. Designers in this area are encouraged to consider the cognitive, affective and behavioral implications of climate change engagement, and to design games in a way that supports their desired outcomes effectively, that is, considering who players are, where they come from, and what they want.

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PUBLICATION IV

**From traditional to game-based learning of climate change:
A media comparison experiment**

Fernández Galeote, D., Legaki, N. Z., & Hamari, J.

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From Traditional to Game-Based Learning of Climate Change: A Media Comparison Experiment

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Widespread climate change engagement is needed to confront our current environmental crises, but it remains difficult to attain. Methods such as visualizations and experiential learning activities, including games and gamification, have been proposed to engage citizens beyond what generic and one-way information sharing can, but rigorous studies comparing the effects of game-based learning with traditional methods are rare. Therefore, this study investigates the effects of a serious game vs. control on learning outcomes related to climate change concepts. We conducted an experiment involving N=105 participants randomly assigned to two treatment groups (a desktop screen-based video game and an immersive VR version of the same game) and a control (a text with charts) and investigated the differences between pre- and post-intervention measures of knowledge. The results show that all three conditions had a large effect on learning, but there were no significant improvement differences between groups. Therefore, video games, either on desktop or virtual reality, may be as effective as more traditional instructional materials. Based on detailed observations of the questionnaire data, we also provide game design recommendations. Future studies could focus on specific features of learning and cognitive engagement, while expanding this experimental design to affect and behavior.

CCS Concepts: • **Applied computing → Interactive learning environments**; **Computer games**; • **Human-centered computing → User studies**.

Additional Key Words and Phrases: gamification, serious games, game-based learning, immersive virtual reality, vr, environmental sustainability, climate change engagement, controlled experiment

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1 INTRODUCTION

The climate crisis threatens both human societies and biodiversity to the extent that urgent action toward reducing greenhouse gas emissions is needed [65]. However, current policies are insufficient to achieve the Paris Agreement warming goal [66]. One of the reasons why climate change is difficult to mitigate is its wickedness, or the fact that its scale and complexity make it both difficult to understand and to act upon in a manner that would be acceptable by all actors [35]. Furthermore, the situation is complicated by the fact that action is urgent, those tasked with its mitigation also contribute to it, and no single actor has enough political power to address the issue effectively, leading to irrational delay [46].

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In parallel to lacking political and economic action, the widespread level of climate change engagement needed to demand and support the necessary changes remains insufficient and difficult to attain [41, 49, 89]. Although public climate change engagement requires a state of connection with the issue that transcends understanding [49], knowledge remains a crucial component as it can provide a meaningful justification for action [49]. Thus, the importance of public understanding of climate change, coupled with the limited effectiveness of top-down information delivery, has led experts to propose consciously framed messages, visual media, and dialogic or experiential methods as effective communication techniques [29, 58, 60, 90].

These recommendations point toward the potential of both immersive virtual reality (VR) as a technology and gamification as an engagement technique for climate change learning and engagement. On the one hand, the simulational aspects of 3D environments can enhance learning [48], especially in immersive VR where people can act and sense within a space [88]. Immersive VR can also allow users to experience abstract and distant concepts such as climate change as tangible and close [12, 53], making them more memorable and emotionally impactful [53]. In addition, immersive VR is often perceived as engaging [70] and typically leads to experiences of presence, or the feeling of being in the virtual space [19], which can positively affect attention, memory and reasoning [70]. Thus, the existing evidence suggests that immersive VR is effective in promoting climate change learning [11]. On the other hand, digital games support effective learning by promoting direct experience and guided inquiry within virtual worlds [58, 75], providing enjoyment and emotional engagement through elements such as stories and characters [34, 75] and motivating through the exercise of competence, autonomy and relatedness [75, 79].

However, our current understanding of the potential of games and immersive technologies for climate change engagement is limited. Game designs and their impacts differ in many ways, as do contexts and audiences that can benefit from their use [29]. Comparisons of climate change games and other media are rare [29], and the existing ones paint a nuanced picture in which games present specific advantages such as retention and engagement [73] or are not significantly more effective than other methods [68, 81]. In particular, immersive VR games for climate change engagement are uncommon [23], as is the evidence of their effectiveness [11].

To paint a more complete and accurate picture of the potential of gameful climate change engagement, more studies, especially controlled experimental designs, are needed [29]. Whereas no single study may be able to provide definitive answers, the accumulation of rigorous evidence is critical for future reviews and meta-analyses seeking to advance our knowledge beyond the current level (for existing reviews see, e.g., [21, 26, 29, 76]).

This study randomly assigned 105 participants to three conditions with the aim of exploring and comparing the learning effects of a text with static charts, a screen-based PC game, and the same game in immersive VR. The text and the game, created for the purposes of this study and titled *Climate Connected: Outbreak*, focus on the connections between climate change causes, its physical manifestations, and its consequences for human and non-human life, particularly the emergence and expansion of infectious diseases and pandemics. Our exploratory null hypotheses include:

- $H_{0.1}$: There is no significant difference between pre- and post- intervention performance.
- $H_{0.2}$: There is no significant difference in post-intervention performance between text readers, PC players, and immersive VR players.
- $H_{0.3}$: There is no significant difference in post-intervention performance between text readers and game players.

The results suggest that the intervention led to large positive learning outcomes, but there were no significant differences between the three groups. The statistical tests are complemented with descriptive analyses of the data to explore what patterns can be found across questions, conditions, and moments of data collection, with the goal of better understanding the details of the participants' learning. Our discussion of these results suggests aspects of the game and the text that may have supported or hindered learning, and proposes design recommendations. Taken together, these results provide insight into the potential of game-based learning for climate change engagement, especially when the goal is to acquire information through single-player narrative games on desktop screens and immersive VR, in comparison with traditional instruction. In doing so, it complements previous efforts by the CHI Play [13, 15, 23, 36, 62, 84] and CHI [24, 61] communities to bring positive impact through technology and games in the fields of environmental sustainability and climate change.

2 BACKGROUND

2.1 Climate Change Engagement

Climate change engagement as a psychological concept can be defined as "a personal state of connection with the issue of climate change ... concurrently comprising cognitive, affective and behavioural aspects" [49, p. 446]. These three dimensions form a complex and nonlinear system where knowledge is an important component but not necessarily a precursor to action or emotion [41, 49, 89]. Furthermore, education and environmental knowledge have been deemed important, albeit not sufficient, for pro-environmental decision-making [31], and even given a secondary role in pro-environmental behavior [41]. However, behavior based on conscious understanding can provide a deeper reason for mitigation measures beyond non-environmental motivations such as financial gain [49].

It must not be forgotten that climate change information interacts with personal and contextual elements, from values and attitudes to economic, social and cultural factors [31, 49, 89]. When faced with a message about climate change, people are subject to biases in attention and perception [50]. In fact, knowledge itself can be seen as a complex construct comprising different degrees–from isolated facts to true comprehension of systems, and from causes to consequences to mitigation and adaptation measures and their level of effectiveness [37, 41].

This complexity, which mirrors that of climate change itself, has sparked decades of research examining the social and psychological barriers preventing action [31, 41, 49, 89]. Accordingly, various strands of research have emerged aiming to understand the keys to promote climate change engagement via various media and message strategies, including frames that make the issue salient for specific audiences (see, e.g., [1]).

2.2 Communicating, Visualizing, and Interacting With Climate Change

In climate change communication, making issues and solutions visual has been hailed as an effective method to promote engagement [80]. Consequently, the role of visuals in this area has garnered research attention, as has the potential of technologies that allow for their effective use [60], in particular information and communications technology (ICT) for interactive visualization [91]. This includes virtual environments such as those enabled by immersive VR technology, e.g., head-mounted displays (HMD). Some cognitive advantages of interactive visualizations are a more efficient use of cognitive capacity, ease of information search and pattern recognition, simplified complexity, and manipulability [17].

3D virtual environments, and immersive VR in particular, present potential advantages for learning through environmental simulation [48]. According to the theory of grounded cognition, cognition can be based on modal simulations, or the mental reenactment of past experiences, among other mechanisms (bodily states, situated action) [5]. This theory and adjacent concepts, such as embodied cognition, posit that our thinking is based on mental representations that our memory captures in a situated way, that is, via physical sensation and environmental perception [5]. According to these theoretical perspectives, sensory-motor impressions remain perceptual in our minds, rather than being transformed into an amodal language (e.g., a list of an object's features) [6]. The involvement of multiple neural networks associated with multiple sensory-motor aspects enriches a concept's meaning and makes it readily applicable in more contexts [33].

In connection with the former, perceptual simulations help promote understanding, and tasks involving direct manipulation tend to be more memorable [8]. For example, past experiences with historical video games have been found to aid symbolic learning (e.g., from reading) of new information [8]. However, not all stimuli related to a concept are equally powerful for learning. For example, good educational visual representations should activate perceptual symbols at the core of the concept represented [14], e.g., showing ongoing changes as a result of stocks, flows, and feedback loops when teaching about systems thinking.

While desktop-based 3D environments can offer multimodal stimuli and interaction, immersive VR typically presents more vivid or realistic sensory information and interactions that involve the body more fully [48] through features such as head and hand tracking. These features allow users to see the 3D environment all around them, move, and manipulate objects using their arms and hands, for example. Thus, more complete and explicit mental representations can be built from more complex body movements and environments offering a variety of modal perceptions (e.g., tactile, in addition to auditory and visual), supporting memorization [48]. As said, rich interactive visualizations can be especially relevant for phenomena that are often perceived as distant and abstract, such as climate change [58, 80].

In addition to the above considerations, engagement can also lead to memorable learning experiences. Comparative studies between immersive VR and other forms of instruction in the fields of science, technology, engineering, and mathematics (STEM) show that VR is typically perceived as more engaging and can support learning by inducing emotions and a sense of presence, which promotes not only satisfaction but also cognitive factors such as attention, memory, and reasoning [70]. The excitement of immersive VR may be at least partially related to the fact that it offers both novel and complex experiences, which tend to elicit curiosity [7].

However, some comparative studies have found limitations. Immersive VR was less effective at teaching science than a slideshow [69] and less [51] or as effective as desktop computer versions of the same content [59], which may be attributed to a higher cognitive load and potential for distraction in VR [51]. Similarly, watching 360° video through an HMD rather than a screen can negatively affect attention and recall because users feel more compelled to explore, which detracts attention from voiceover narration [4]. When information in immersive VR is presented as text, readability can also be poor due to low resolution [38], which can result in tiredness.

In the field of climate change communication, the fact that immersive VR tends to be more enjoyable and immersive than other media also has specific implications for climate change engagement, since such states of cognitive absorption may counteract biases based on previous beliefs and motivations [50]. Previous research on the potential of VR for environmental communication shows mostly positive findings when attempting to impact attitudes and behavior [11]. HMDs, computers and mobiles can simulate experiences such as immersive VR field trips and 360° spatial explorations, which can promote learning about climate change [53, 54] and other environmental topics, even to a higher degree than conventional teaching materials [67]. Immersive media such as 360° videos can increase the salience of distant issues [12], which is especially relevant for climate change. A sense of presence, which more immersive technologies tend to elicit [19], can support learning about climate change and increase environmental concern [54], although a direct effect of presence on learning was not observed in a study comparing 360° video-based climate change news on an HMD, a screen, and a text with pictures [3].

In summary, visual and interactive media, and immersive VR in particular, present potential advantages for learning about climate change, although the evidence and learning effect comparisons with other media are limited [11]. Given the multiplicity of contexts and audiences relevant to climate change learning and the disparity of outcomes, more comparisons with other instruction and communication methods are needed.

2.3 Games and Gamification for Climate Change Engagement

Beyond climate change visualization, experts have proposed a shift from one-way communication towards dialogic processes [60, 90] and other methods where people are given a chance to build knowledge on their own terms [58]. These recommendations imply that experiential methods such as games and gamification harbor a potential for climate change engagement.

Game-based learning describes the use of games, whether designed as educational artifacts or not, to engage players in learning activities that incorporate the topic as part of a game system. Players typically engage with the system through a role, making choices and confronting the consequences [72]. Meanwhile, the term “gamification” has often been used to describe the application of game design elements in non-game contexts, as opposed to full-fledged games [20]. However, gamification is also used as an umbrella term for any transformation of activities or systems to afford game-like experiences to support change, including serious games and game-based learning [32]. While this study uses terms such as game or game-based learning when precision is needed, it adopts the conceptualization of gamification as a term referring to any form of gameful engagement, as has been done in climate change engagement literature [21, 29, 76] and more broadly [40, 42].

The use of digital game-based learning includes the advantages of exploring visual climate change through virtual worlds and the possibility of learning through direct experience and inquiry [58]. Beyond this, games can also adapt to player performance, not only maintaining an adequate challenge level but also supporting learning [75]; elicit strong emotional engagement with events, stories, and characters [34]; and motivate players through intrinsic and extrinsic means [75] to continue engaging with the game and even to change their behavior.

Desktop 3D game learning environments have been found to be more effective than technically similar virtual worlds or simulations [56] and traditional instruction, especially when they span multiple sessions or are combined with other methods [92]. Various digital games have successfully promoted learning about climate change [29]. In the field of human-computer interaction, several scholars have presented their gamified pro-environmental contributions in venues such as CHI and CHI Play, including gameful science communication [61], a climate action simulation game [13], and educational games about climate-related biodiversity issues [10, 62], energy [2], mobility [27], sustainable production [77] and other topics, sometimes involving methods such as solar-powered wearables [15], playful artifacts [36], and social learning environments [43, 52, 57]. The creation of games as part of climate science education has also been explored [84], as well as the analysis of existing ones in search for climate change engagement potential [23, 24].

However, the field of applied games lacks media comparison studies involving games and control conditions with similar informational content [81]. This includes the area of gamification for climate change engagement [29]. When comparisons exist, games’ advantage may be either non-significant [68, 81] or affect specific features of learning such as retention, in addition to being more engaging [73]. Furthermore, immersive VR is rarely used in game-based climate change engagement [23], despite having received attention as a visual climate communication tool.

Table 1. Participants' distribution per age group

Age group	n	$n_{control}$	n_{PC}	n_{VR}
18-20	8	1	6	1
21-25	33	12	9	12
26-30	26	8	10	8
31-35	16	7	4	5
36-40	14	6	3	5
41-45	2	1	0	1
46-50	4	0	2	2
>50	2	0	1	1

3 METHODS AND MATERIALS

3.1 Participants

An in-person experiment was conducted at the authors' university. The final sample was N=105 participants divided into three groups: text with static charts (hereafter control, n=35), screen-based PC game (hereafter PC, n=35), and the same game in immersive VR (hereafter VR, n=35). Their average age was similar in all three groups (control: 29.29; PC: 28.57; VR: 30.63; see Table 1), as was their gender distribution (control: Female=20, Male=14, Other=1; PC: F=20, M=14, O=1; VR: F=21, M=13, O=1).

The participants' highest educational level attained included primary education (n=1), vocational school or course (n=2), general upper secondary education (matriculation examination) (n=10), vocational college (post-secondary) (n=1), university of applied sciences bachelor's degree (n=14), university of applied sciences master's degree (n=2), university bachelor's degree (n=27), and university master's degree (n=48), which was the highest option allowed. The number of participants with university education was similar across conditions (control: 31; PC: 29; VR: 31). In terms of their areas of origin, Finland was the most frequent (n=35), followed by Asia (n=24), the EU (n=23), the US or Canada (n=5), non-EU Europe (n=4), Africa (n=3), Middle East (n=3), and Latin America (n=2). No participants came from Oceania. Six participants came from areas other than the above.

3.2 Materials

All materials were designed for the needs of this study and provide an understanding of the connections between climate change causes; physical manifestations; impacts on biodiversity and human societies, in particular infectious diseases and pandemics; and mitigation actions. The materials include a questionnaire, answered by all participants before and after the intervention; *Climate Connected: Outbreak*, a digital game for desktop PC and VR created by the first author using the Unity engine (version 2020.3.19f1); and a text document adapting the game's informational material and flowcharts. All the materials were in English and are described in more detail next.

3.2.1 Pre- and Post-test. The pre- and post-test instrument is a 14-question questionnaire (available in [28]) created to address the learning objectives and the content of the game and the text. Three answer options were given: true, false, or "I don't know." All three groups answered the same questions, which were presented in a different order pre- and post-intervention. In accordance with the game and text contents, the 14 questions focus on the causes of climate change, its physical impacts such as sea level rise and droughts, its connection with pandemics, the origin of most human diseases, the effects of climate change on infectious disease vectors and other animals and life forms, the use of cereals in the world, possible forms of climate action, and the implications of using air conditioning for climate adaptation.

3.2.2 Game System and Control. The game's design considers recommendations and gaps identified in the games for climate change engagement literature [23, 24, 29]. Thus, it frames climate change as a health and wellbeing issue, which is an underexplored [85] and potentially engaging [1, 86] approach; frames the player as a citizen with many capabilities beyond consumer behavior [82, 90]; and promotes real-world action. *Climate Connected: Outbreak* underwent multiple testing iterations on PC and VR before arriving at the one used in this study (for studies based on a previous PC version, see [22, 25]).

Content description. The game's content seeks to reinforce three forms of knowledge: declarative, including awareness of climate change facts and understanding of systems; procedural, which refers to actions that can be taken; and effectiveness, which gauges the mitigation potential of different actions [37]. Information about climate change and infectious diseases from dozens of scientific and educational sources (e.g., [39, 65, 74]) was included. In addition, three experts were consulted about the accuracy of the content during the development process and their suggestions were implemented. They were a doctor in atmospheric sciences with expertise in global change and science communication; a professor of aerosol physics in charge of teaching a course about climate science; and a sustainability and environmental policy researcher and lecturer.

The information is presented as part of an interactive story that, following climate change communication best practices [80, 90], puts the player and the fictional local space at the center, visually framing climate change as critical to human and environmental well-being and connecting day-to-day habits and elements to its causes, consequences, and mitigation. Before proposing any actions to the player, the game asks them about their position towards climate change and offers adapted motivational support [78] mainly based on self-determination theory [18] and environmental amotivation-countering practices [71]. Then, players can choose to act in the real world in multiple ways (action sources include, e.g., [82, 90, 93]) according to their preferences.

PC and VR gameplay design. The game features simple mechanics: select dialog options (i.e., self-paced progress through textual information with occasional choices resulting in small feedback variations), navigate 3D spaces using a teleporting system, and interact with objects (select, grab and throw). On PC, the left mouse button is used for all actions; in VR, a trigger in the controller is pressed. However, VR allows for more complex and physically involving forms of interaction: for example, in the various minigames that require manipulating and throwing objects, VR players can grab them by pointing at them and holding the trigger, as well as throw them with an arm motion while releasing the trigger. The one-button interaction, as well as the natural gestures in the immersive VR version, were chosen to provide comfort to those unfamiliar with digital games and/or immersive VR. The fact that players could use any of the two VR controllers provided aimed to accommodate both right- and left-handed users, and teleportation was chosen as a locomotion method that minimizes the possibility of motion sickness.

The player engages with the game's linear story across four sequential chapters:

1. A Dreadful Future. The introductory chapter presents the game's setting and goal. The game begins in the year 2050, with the player looking at a sustainable city from the balcony of their apartment, located in a distant town. However, the positive picture soon turns into a much more negative one where the air is polluted, and the land is barren soil and concrete. Then, a spirit of nature appears, tells the player that a pandemic rages on in this future world, and proposes to go on a journey around the apartment to find its origin; that is, the connections between climate change and infectious diseases. As a tutorial, the player is tasked with finding two easily identifiable elements, hand sanitizer and a face mask; playing a minigame associated with each, i.e., applying

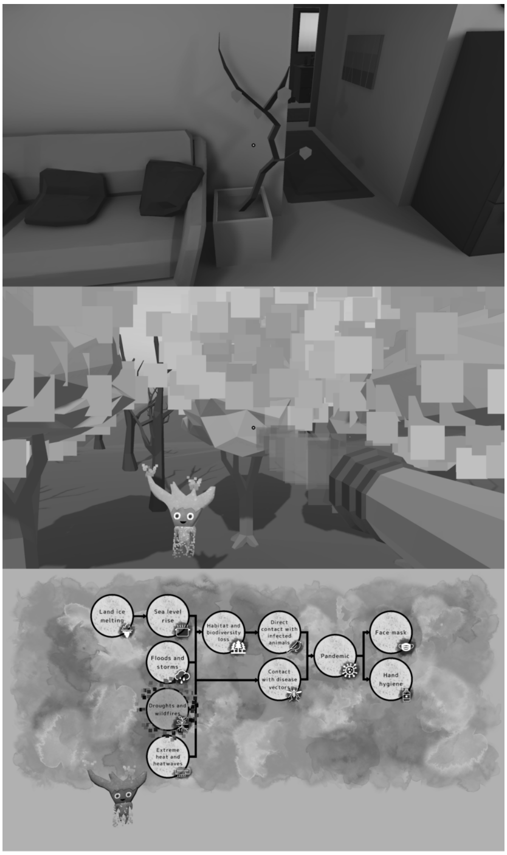

Fig. 1. Three important moments in the gameplay loop: finding an object, playing the corresponding minigame, and seeing how the new node fits in the flowchart.

sanitizer to their hands and masking people around them; and seeing the relevant concept added to a flowchart. These three steps (finding an object, playing a minigame, and completing the flowchart) constitute also the second chapter's basic gameplay loop, as can be seen in Figure 1.

2. Connections. The spirit of nature declares that it is time to start tracing back the connections from consequences to causes. In this chapter, the player navigates the apartment finding 12 more items representing nodes that connect the causes of climate change with pandemics. Once an item has been found, the player completes a corresponding minigame (e.g., escaping environmental degradation as a bird or finding places where mosquitoes can breed after a flood). Then, the node corresponding to the issue just seen is added to the flowchart, which keeps growing as the game progresses. Hence, the textual information is provided by a character, and the main concepts are reinforced with interactions and visual elements and environments. Additional descriptions of the minigames and their relationship to the knowledge tested can be found in the results section, where they contextualize some of our findings.

3. The Full Picture. Once all the elements are in place, the guide quizzes the player about them, from the causes of climate change to its various impacts on human and ecosystem wellbeing.

4. What Can We Do? The spirit of nature presents climate action as a good way to address the causes of many pandemics rather than adopting only a reactive stance. Then, the player is invited to express their feelings towards the game's content, including how much they believe in and care about it. If they choose to share their doubts or issues preventing them from acting, the spirit of nature provides some additional considerations and arguments. Then, if players agree to engage in one form of climate action, they are shown different possibilities, including information sources from which to learn more and ways of acting individually and collectively. If they choose one, they are sent an email after the experiment with further ideas.

The game's design incorporates some game-based learning principles as described by Gee [30]. These include the player taking an identity, in this case a possible future self; interacting with the game world, i.e., acting and receiving feedback; producing the story through interaction (i.e., progressively building the flowchart by finding objects and playing minigames); linking concepts to experiences, i.e., offering situated meanings; promoting lateral thinking by presenting common elements in a new light, that is, as symbols of climate-related phenomena; in the same way, focusing on systems thinking through the flowchart; attempting to be well-balanced in terms of difficulty, for which playtesting was conducted; providing relevant information at strategic points; and presenting the quiz as a challenge for knowledge consolidation only after the player has had the opportunity to learn all the connections. However, as a linear story-based single-player design, the game does not focus on offering other principles such as customization, character knowledge that the player would not have on their own, progressive difficulty focused on skill development, learning from failure, multiplayer features, and ample autonomy, since the game offers one learning path even though players can choose their desired action type at the end [30].

In addition, some principles of multimedia learning have been taken into account [55]. The game makes use of both text and visual environments; relevant words and graphics are presented simultaneously and closely; we avoid complicated language as much as possible, in part thanks to the playtesting process; we signal the game's chapter structure to players and the flowchart serves as a progress map; and the content is segmented based on discrete concepts. Although the addition of background music is not recommended due to it being potentially distracting from the content [55], the game does not have audio narration, so there is no direct competition within the auditory channel; furthermore, playtesting of earlier game versions suggested that players expect games to have music, even if, as it is the case, it is rather soft and non-intrusive.

Text-based control. To compare the learning effects of playing the game to reading a text, we created a PDF document containing the textual information in the game, the flowcharts, and descriptions of the fictional world matching what can be seen in the game (e.g., "Your town in the year 2050 is part of a clean, healthy, green world. From your balcony, you see a grassy road below where electric trams pass, bicycles stationed under trees, an urban garden, wind turbines moving."). Thus, the 4,600-word text narrates a story in which the reader is addressed directly, but no interaction exists. Any information that could have been acquired by playing the minigames is described instead, and the author's voice in addressing the reader, while present as in the game (e.g., "I wanted to share a simple idea with you"), lacks a defined character. The quiz in chapter 3 has been replaced by a written account of the right answers, and the questions about the player's feelings in chapter 4 are just described in sequence, accounting for every option that the participant may be interested in (e.g., "Maybe you feel none of this has much to do with you," followed by the corresponding response). The only part that had to remain interactive, choosing an action at the end and receiving an email about it, has been offset to a questionnaire form provided to the participants after reading, and is clearly separated from the document reading activity.

3.3 Procedure and Experimental Design

The lab experiment's aim was advertised as immersing participants in different forms of climate change information to gather insights on their experience and outcomes so that the communication methods' effects could be understood. The study was advertised through digital and physical (i.e., leaflets and posters) channels related to the university and the city. Participants were informed in advance that VR may be used so they should not wear glasses if possible. At the end of the session, participants were also encouraged to ask their acquaintances to participate without disclosing their experience. The study was open to any adult who provided their informed consent, complied with national ethical guidelines, and was approved by the university's data protection officer.

Participants were randomly assigned to one of the three groups before arriving at the site. The researchers only balanced the groups towards the end of the data collection to ensure that the gender distribution was similar. This was done because gender differences have been observed in environmental attitude, concern and behavior, whether due to personality tendencies, social norms and practices, identity, or other factors [9, 31]. While gender is but one of the personal and social variables that may affect an individual's climate change engagement [31], its classification as just three values in this study made it simple enough for it to be considered in the experimental design, and the added complexity of balancing multiple additional variables would have exceeded our available resources. As said above, age and educational level, which are also potentially relevant personal factors [31], were similar across groups as well.

The experiment included the questionnaire and two other tasks before and after playing the game or reading the text. The other tasks did not provide information that could interfere with the questionnaire's outcomes. The questionnaire was answered by all participants before and after reading or playing. The questions' order was presented differently before and after. Participants were given a maximum of 10 minutes to answer the questionnaire, but all were finished earlier.

After this, the respective activity was described to the participants along with the goal–to "get as good an understanding as possible of the content of the game/text" because they would be asked some questions about it afterwards. Participants who read the text or played the PC game stayed in the same computer, while VR participants moved to a different space where they would use Oculus Quest 2 with two standard controllers. Participants were informed that they had between 30 and 60 minutes to complete the game.

They were told that if 60 minutes were reached, they would be invited to finish as soon as possible. During the intervention, participants were notified when 30, 45, 55, and 60 minutes had passed. Text readers were told that, if they finished before 30 minutes had passed, they would be free to re-read any part of the text until the minimum time had been reached. PC and VR players were told about the game controls. Text readers took an average of 32 minutes to finish; PC players completed the game in 40 minutes on average; VR players finished in 43 minutes.

4 RESULTS

4.1 Statistical Test Results

To test our hypotheses, we first statistically examined whether the intervention had improved knowledge. Then, we compared the learning outcomes between the three groups. As a descriptive summary, Table 2 includes the participant performance per group before and after the intervention.

To analyze the data, participant performance for each test was calculated as the sum of correct answers, as previous studies of climate change knowledge have done [44, 45]. Figure 2 depicts the number of correct answers before and after the intervention for all three groups, and Figure 3 shows the difference, i.e., post minus pre.

Table 2. Participants' performance per group, before and after. For each measure, the table includes the correct answers' mean (M) and standard deviation (SD); total correct (Cor.), incorrect (Inc.), and "don't know" (NA) answers; and pre- vs. post-test change

Group	N	Pre-test					Post-test				
		M	SD	Cor.	Inc.	NA	M	SD	Cor.	Inc.	NA
Control	35	9.66	2.21	338	59	93	11.6	1.67	405 (+19.82%)	61 (+3.39%)	24 (-74.19%)
PC	35	9	2.17	315	62	113	11.5	1.6	404 (+28.25%)	63 (+1.61%)	23 (-79.65%)
VR	35	9	1.96	315	80	95	11.4	1.73	398 (+26.35%)	78 (-2.5%)	14 (-85.26%)

A one-way ANOVA test (Fisher's) was conducted to ensure that no significant differences existed in the initial number of correct, incorrect, and NA answers between the three groups. Having verified that the data for correct answers were normally distributed and the variances homogeneous, the test indicated that no significant differences seem to exist between the groups before the treatment, $F(2,102) = 1.127$, $p = .328$. Shapiro-Wilk tests and visual examination of Q-Q plots suggested that the data on incorrect and NA answers is not normally distributed. Therefore, Kruskal-Wallis tests were conducted. No significant differences seem to exist between the groups in terms of incorrect answers before the treatment, $H(2)=4.51$, $p=.105$, nor for NA answers, $H(2)=1.33$, $p=.515$.

A homogeneity of variances test (Levene's) and Q-Q plot examination suggested that the variances across groups are equal and the standardized residuals of the model are approximately normally distributed. Thus, a repeated measures ANOVA was conducted to determine the effect of the intervention on learning and possible differences between groups. The treatment significantly increased the number of correct answers from before (M = 9.22, SE = .21) to after the treatment (M = 11.5, SE = .16), $F(1, 102) = 156.04$, $p < .001$, ${\eta^2}_G = .269$, $\eta^2 = .266$ (large effect [16]), ${\eta^2}_p = 0.605$. There was not a statistically significant difference in knowledge acquisition between treatment groups ($F(2, 102) = 0.654$, $p = 0.522$).

Although the overall standardized residuals seem to be normally distributed, some of the individual factor levels involved in the analysis seem not to be, based on Shapiro-Wilk test results and visual examination of Q-Q plots. While parametric analysis of variance tests such as repeated measures ANOVA can be considered robust for non-normally distributed data [63], we complemented our analysis for additional robustness with non-parametric alternatives: Wilcoxon rank tests and non-parametric ANCOVA. The result of the Wilcoxon rank test for the whole sample indicates a significant difference between correct answers before the intervention (M=9.22; Mdn=9; SD=2.12) and after the intervention (M=11.5; Mdn=12; SD=1.65); [W = 39, p < .001, d=0.98 (large effect, according to the guidelines in [16])]. Wilcoxon rank tests also suggest significant differences in the control group between before (M=9.66; Mdn=10; SD=2.21) and after (M=11.6; Mdn=12; SD=1.67); [W = 9, p < .001, d=0.952 (large effect)]; in the PC group between before (M=9; Mdn=9; SD=2.17) and after (M=11.5; Mdn=12; SD=1.60); [W = 0, p < .001, d=1 (large effect)]; and in the VR group between before (M=9; Mdn=9; SD=1.96) and after (M=11.4; Mdn=12; SD=1.73); [W = 6, p < .001, d=0.976 (large effect)].

As a complement to the between-subjects part of the repeated measures ANOVA, a non-parametric analysis of covariance (ANCOVA) was conducted using the fANCOVA package (version 0.6-1) [87] in R (version 4.2.2), controlling for the participants' initial level of knowledge. The test used the T.aov function to compare three non-parametric regression curves calculated based on

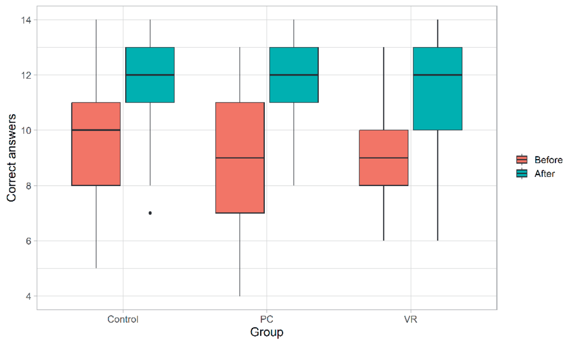

Fig. 2. Correct answers before and after the intervention per group. All three conditions' median values increased after the intervention (12, up from 9 and 10), with the lower quartiles taking the value of the former higher quartiles.

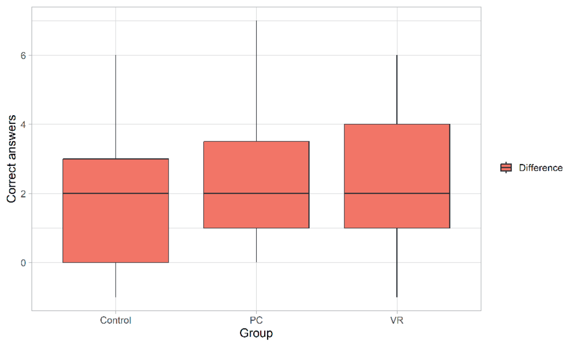

Fig. 3. Difference in the number of correct answers before and after the intervention per group. A median improvement of 2 points can be seen in all three. None of the lower quartiles are negative.

polynomial regression with automatic smoothing parameter selection via AICC for curve fitting. There was not a statistically significant difference in post-test correct answers between the groups, T = 0.025, p = 0.970.

Therefore, based on the within-subjects part of the repeated measures ANOVA and the Wilcoxon rank test, we reject the null hypothesis "$H_{0.1}$: There is no significant difference between pre- and post-intervention performance." The intervention had a large positive effect on the learning outcomes. However, based on the between-subjects part of the repeated measures ANOVA and the non-parametric ANCOVA, we cannot reject "$H_{0.2}$: There is no significant difference in post-intervention performance between text readers, PC players, and immersive VR players."

We also classified the data in two major groups, control (n=35) and game (n=70, PC and VR together) to examine the overall impact of the game treatment. A repeated measures ANOVA did not find any between-subjects effects, F(1, 103) = 1.27, p = 0.262. This test was also complemented with a non-parametric ANCOVA controlling for the participants' initial level of knowledge. There was not a statistically significant difference in post-test correct answers between the groups, T = 1.195, p = 0.587. Thus, the null hypothesis "$H_{0.3}$: There is no significant difference in post-intervention performance between text readers and game players" cannot be rejected.

To test whether other forms of scoring would have led to significantly different results, we conducted the same statistical tests using two additional scoring systems–subtracting 0.5 points and 1 point for each incorrect answer. This procedure, known as sensitivity analysis [83], yielded no meaningful differences in statistical significance–changes between before and after were significant across scoring methods, whereas differences between groups remained non-significant.

4.2 Descriptive Examination Results

Next, in addition to the statistical inferences above, we describe the data in more detail to see how participant responses changed after the treatment. The data for all participants and the breakdown by conditions can be found in [28]. We classified pre-post answer pairings as positive changes (wrong-right, NA-right, wrong-NA, assuming that uncertainty is preferable to inaccuracy), neutral (same before and after) or negative (right-wrong, right-NA, NA-wrong). We observe that, of 1470 pairs of responses (14 questions times 105 participants), 19.3% represented an improvement, 74.3% stayed the same, and 6.4% changed negatively. The data within each condition were similar in all three directions (control: 16.5%, 78%, 5.5%; PC: 21.2%, 72.7%, 6.1%; VR: 20.2%, 72.2%, 7.6%). Although the improvement for PC and VR players was larger than that of readers, they had less accurate answers before the treatment. As can be seen in Table 2, the final number of correct answers was almost identical in all conditions. The largest source of positive change in the participants' answers was from NA to correct (74.5% of positive change) and the largest source of negative change was from NA to wrong (59.6% of negative change). This was the case in all three conditions. Thus, the change was in most cases positive but not always, as there were in total 203 changes NA-correct versus 56 from NA to incorrect.

The accompanying artifact also contains the aggregate participant answers by question, before and after [28]. Four of the fourteen questions were answered correctly by over 90% of the participants already before the intervention: "Q5: Climate change can cause animals to become stressed, sick, displaced, and extinct," "Q9: Life under water is protected from climate change, which only affects the atmosphere," "Q10: Climate change is increased by human activities emitting greenhouse gases such as CO2 and methane, which trap heat in the atmosphere," and "Q12: Some forms of energy generation do not involve directly burning fossil fuels." This occurred across all conditions, the exception being 88.6% of correct answers for Q12 in the VR group. Nonetheless, the data suggests that almost all participants had at least a basic understanding of the cause of anthropogenic climate change, its impacts on biodiversity, and one of the main forms of mitigation, i.e., the use of low-carbon energy sources.

Six other questions were answered correctly by over half of the participants before the intervention. These are "Q1: There is no link between climate change and infectious disease outbreaks" (74.3%), "Q2: Regular people can only act on climate change by consuming differently in areas such as food and energy use" (78.1%), "Q4: Despite climate change, mosquitoes that carry diseases will stay exclusively in tropical areas" (65.7%), "Q11: Human technology is the only way to take greenhouse gases out of the atmosphere once they have been released" (69.5%), "Q13: Air conditioning helps us survive climate change, but it also releases greenhouse gases that make it worse" (64.7%) and "Q14: Most cereals grown in the world are for direct human consumption" (50.5%). The results across groups were similar, except for Q14 (control: 68.6%; PC: 48.57%; VR: 34.3%). When observing the post-treatment answers, some differences appear between conditions, particularly in Q2, in which VR participants did comparably worse (control: 91.4%; PC: 94.3%; VR: 77.1%); Q11, where less PC players answered correctly (control: 94.4%; PC: 74.3%; VR: 85.7%); and Q13 and Q14, in which fewer text readers answered correctly when compared to the game groups (control: 88.6%, 80%; PC: 97.1%, 88.6%; VR: 97.1%, 97.1%).

The answers to these questions were given in different ways in the game. Demonstrating Q1 was the essence of the game, as the whole process aimed to show the links between the two concepts; Q2 appeared mostly within the final chapter, in which players could select forms of action that were different from individual consumption. Q4 was explained and exemplified through two minigames in which players had to place a mosquito net and find and remove mosquito breeding grounds. The concept that makes Q11 false, natural carbon sinks such as oceans and forests, was explained through text after a minigame in which players watered crops that were eaten by a cow, which was used to explain Q14. Finally, Q13 was explained and shown through a simple minigame in which players had to turn on and off an air conditioning unit.

The remaining four questions were correctly answered by less than half of the participants before the intervention: "Q3: Most human diseases begin when a person's DNA gets corrupted and develops a new virus, which is then transmitted to other people." (45.7%), "Q6: The global sea level is expected to rise at the same rate over the 21st century as it did during the 20th century, but climate change mitigation can slow it down before 2050." (34.3%), "Q7: Since mosquitoes prefer warmer temperatures, storms and floods severely destroy their habitats." (47.6%), and "Q8: Droughts, or an extended lack of rain, have become more common everywhere in the world due to climate change." (11.4%). Of these, Q3, Q6, and Q7 saw noticeable improvement (20-25% more correct answers), although VR players did comparatively worse in Q6 after playing (control: 65.7%; PC: 60%; VR: 48.6%). Meanwhile, the number of correct answers to Q8 grew only marginally in general (1.9%). This suggests that the intervention raised awareness of the origins of infectious diseases, the dynamics of sea level rise, and the conditions in which mosquitoes thrive, but it did not clearly communicate the idea that climate change will affect different places on Earth differently, not necessarily leading to droughts everywhere (as can be seen in [65] and is explained in the questionnaire file [28]). Game players' answers to Q8 improved less than text readers', and in fact fewer VR players answered correctly the second time (control: 22.9%; PC: 11.4%; VR: 5.7%).

In the game, Q3 was explained through text and exemplified via various minigames in which players embodied a bird escaping environmental degradation and arriving to a city; protected from mosquitoes by placing a net over a door; and destroyed the habitat of a river mammal to build human infrastructure. Q6 was shown through a minigame in which the sea level rose in front of the player for different periods of time between 1901 and 2100. Q7 was explained and shown through a minigame in which players had to find and remove mosquito breeding grounds. Finally, Q8 was explained only textually before playing a forest fire-extinguishing minigame that was intended to show that, in contrast with the game's main city where it was raining, other places of the world suffer more droughts and wildfires than before.

5 DISCUSSION

This study has compared the learning effects of three different stimuli: a game experienced in immersive VR, the same game on PC, and a text with equivalent informational content. Our observations indicate that all three groups significantly improved their knowledge as measured through a 14-question test. However, according to repeated measures ANOVA and non-parametric ANCOVA tests, these knowledge gains were not significantly different.

5.1 Lack of Differences Between Groups

The non-significant difference between the three groups contrasts with the advantages typically attributed to game-based learning in comparison to traditional instruction methods. However, various aspects of the text, the game, the measurement method, and the participants may be related to the non-significant result.

First, the control condition combined textual information with schematics; that is, static images that provided an overview of the system being described. Therefore, it contained affordances that aimed to represent what one may find in written media as best as possible. In addition, the information was presented as a narration involving the participant in the second person. Thus, the text, while not interactive and lacking the visual 3D elements of the games, could be perceived as reasonably clear and engaging.

Second, and since it conveyed the same explicit information as the control condition, the game was largely text-based. The 3D environments, object-seeking tasks and minigames were intended to represent the concepts in a clearer and more memorable way through direct experience (i.e., via observation and manipulation), and to provide enjoyment and rest in between bits of textual information. However, to keep the experimental design fair, they provided no additional information relevant to the knowledge test. Therefore, a large part of the cognitive engagement that players may have experienced could also be experienced with the control. Thus, while immersive VR may have promoted presence to a larger extent than the PC game, and PC than text, as is to be expected from their affordances [19], the difference may not have been sufficient to result in a detectable learning difference. In fact, increased presence does not always lead to increased learning [3]. Furthermore, the existence of extraneous material, or elements that divert attention from the learning content, can have a detrimental effect [69]. Although font sizes were tested and adjusted for legibility during development, the use of an HMD may have also limited some participants' performance since reading can be tiring or difficult due to blurriness [38] and they had to carry the device's weight while standing up for 30-60 minutes.

Third, the learning measurement method was a relatively short list of questions aimed at capturing the participants' knowledge of multiple aspects related to climate change and pandemics, which may have been insufficient to assess deeper or more complete forms of understanding, including complex systemic relationships and transfer from the text/game to the participants' experience, usual behaviors, and future intentions. Following grounded cognition [5], it can be argued that the immersive VR stimulus may have been a more complete and realistic source for mental conceptualization, and the PC game than the text. However, the assessment of fact-based knowledge immediately after the stimulus may not have captured nuances that would manifest later, or in other forms of cognitive engagement. Thus, all three media were similarly effective according to the kind of assessment conducted, but there could be differences in other forms of learning.

Finally, the participants took part voluntarily in an experiment advertised as about climate change information. While a small compensation was offered (a movie ticket), many were likely motivated to learn about the topic, and thus probably interested in reading about it. The sample was generally highly educated, which is another particularity that may be expected from a study conducted in a university and advertised mostly around it but is not necessarily representative of other contexts where climate change engagement is also desirable. The enjoyment and curiosity-related advantages of using a game and immersive VR [7, 34, 75] could be more salient for audiences less interested in reading about climate change.

These considerations open the door for exploring effects other than learning outcomes. While the effects on quiz performance may have been similar between the conditions, participants in the game-based treatments could show heightened constructive attitude towards climate change issues as well as future intention to act. Moreover, it is possible that the learning experience might have been more enjoyable in the game-based treatment conditions which, ceteris paribus, would make the game-based versions of the instructional material preferable.

5.2 Descriptive Data Examination

Our observation of the data as a complement to the statistical analysis revealed aspects of interest in the participants' response patterns. These observations are taken as a starting point for the following discussion, which suggests, in turn, ideas to test in future designs and to validate through qualitative and/or quantitative inquiry.

The analysis revealed that despite the lack of statistical differences between groups, the intervention greatly increased the number of correct answers while reducing uncertainty, as shown in Table 2. All three conditions similarly succeeded in this. However, the overall number of wrong answers remained similar. Given that sustainability issues are embedded in our daily life, successfully managing them may require a process of unlearning old ways before adopting new schemata and behaviors [64], which is challenging even at the most basic level of trying to correct misinformation [47]. This means that the difference between not knowing, on the one hand, and being wrong but thinking that one knows, on the other, can be important.

In this respect, and while the intervention decreased uncertainty, the fact that part of the change was negative suggests that neither the text nor the game were interpreted unequivocally by participants. This indicates that climate change communicators should emphasize clarity when presenting scientific facts, perhaps repeating them, providing salient examples, and making sure that visualizations and interactions are in line with the takeaway message [14]. This may be especially true for facts that the general public is unlikely to have encountered before or tends to misconceive, as there was a large difference in the rate of correctness between questions about basic climate change facts and other issues.

Although the sample size within each condition is limited, some questions saw noticeable differences across groups. Q2, which asked about forms of climate action besides personal consumption, was answered correctly by fewer VR players than participants in the other two conditions (control: 91.4%; PC: 94.3%; VR: 77.1%). This may be related to the fact that the climate action segment of the game came at the end, when some participants may have been tired or rushed and thus less likely to pay as much attention to the game. In addition, this part was chiefly communicated via text. Although players explicitly chose from a menu of six actions, only one of which was related to individual consumption, there was little in the way of interactive and visual examples to reinforce the message that all of them were valid forms of action, besides a transformation of the 3D environment from negative to positive after choosing. Thus, designers are encouraged to consider the effects of gameplay over time, and to explicitly reinforce their messages through visualizations and interactions in which a message's implications are clear and explicit.

Another question where some differences were observed is Q6, which asked about the rate of sea level rise in the 21st century and the possibility to slow it down before 2050. Here, VR players did comparatively worse than the rest after playing (control: 65.7%; PC: 60%; VR: 48.6%). Although the question is complex due to it containing two statements, the most obvious fact rendering it false is that sea level rise is forecasted to be faster in the 21st century than in the 20th. Since both PC and VR players experienced a minigame in which the sea level rose in front of and around them for various periods of time, VR players may have been distracted to a larger extent by their flooded surroundings, paying less attention to the numerical data. This possible explanation would be in line with observations that VR can distract learners from the content and result in a higher cognitive load [4, 51]. In addition, players just needed to press continue to see the next phase, so in contrast to other minigames, no explicit attention or effort was required to continue. Therefore, we suggest that designers integrate data within visual and interactive experiences in a way that paying attention is required to progress, ideally making their apparent comprehension part of the gameplay loop.

Question 8 asked whether climate change has already made droughts more common everywhere in the world. A minority of the participants (13.3%) answered in line with the game's message and with the latest evidence [65] even after playing. This may be related to the common idea that global warming results in a reduction in precipitation, no matter where in the world. Although few participants answered correctly in all conditions, game players improved less than text readers, and in fact fewer VR players answered correctly the second time (control: 22.9%; PC: 11.4%; VR: 5.7%). This may be due to the fact that the explanation that some places have not necessarily seen a rise in droughts was followed by a minigame in which players had to extinguish a forest fire. Between the text explanation and the interactive, visual, and perhaps even stressful experience, it is likely that players remembered better the second. Therefore, and especially when considering potential deeply rooted misconceptions or very specific scientific evidence, as is the case, we recommend that designers align their most important message with what players do, since the most stimulating and action-oriented experience will likely be the one that will be remembered according to the theories of embodied and grounded cognition [5, 6, 48]. In this case, the inclusion of an action minigame may have succeeded at reminding players, in a more embodied way, of what most of them probably knew already; that is, that climate change impacts can be dire. However, the more nuanced idea, which is that these dire impacts are not the same everywhere, may have been lost to many.

Regarding Q11, which asked about forms of greenhouse gas sequestration that do not depend on human technology (e.g., forests, oceans), less PC players answered it correctly than other participants, and text readers outperformed game players (control: 94.4%; PC: 74.3%; VR: 85.7%). This question was mostly answered in the game through a text-based explanation after a minigame in which a cow ate crops grown by the player. Although there was a connection between deforestation for agriculture and stockbreeding in the minigame, the interaction focused on the fact that most cereals are grown for industrial and animal feed purposes rather than for human consumption, whereas the issue of deforestation was only textually explained and implied by the presence of a farm. This suggests that even when a concept is reinforced with visual and interactive stimuli, the implications should be made obvious through environmental cues and player actions, rather than remaining in the conceptual vicinity.

In contrast, questions 13 and 14, which ask about the environmental impact of air conditioning and the rate of cereal consumption in the world, respectively, were more accurately answered by game players than text readers (control: 88.6%, 80%; PC: 97.1%, 88.6%; VR: 97.1, 97.1%). Since these were associated directly with player actions and game feedback in minigames (in one, players had to turn off an air conditioner; in the other, described above, a cow kept eating the player's crops), we recommend once again that designers try to encapsulate what is essential to the message in their gameplay, no matter how simple the mechanic or feedback, to create a memorable connection with learned concepts through these actions and stimuli, in line with embodied and grounded cognition [5, 6, 48].

5.3 Limitations

Limitations of this study may have affected its results. First, participants did not only answer these questions, but also engaged in other tasks as part of the pre- and post-treatment data collection process. While all participants completed these in the same order, they could have affected their performance depending on their tiredness, as well as prompting thoughts relevant to the test.

Second, to conduct statistical tests a choice of how to count correct, incorrect and NA answers had to be made, which introduces a degree of arbitrariness. However, the choice to simplify scoring as the sum of correct answers mimics pre-existing large-scale survey research [44, 45]; we have separately provided the number of right, wrong and NA answers in Table 2; shared the original dataset [28]; and tested other grading systems to confirm that they would lead to similar statistical results.

Third, the questions presented before and after the treatment were the same. Although they were reordered and participants were not informed of their performance at any point, the fact that they had seen them before may have had undesired effects. Future studies may use different but comparable questions, or add an additional post-test only questionnaire to avoid familiarity. However, these methods may also have limitations–the comparability of different questions should be convincingly justified, while post-test only questionnaires allow to infer differences between groups but not improvement.

Fourth, it should be remembered that the game used has characteristics (e.g., linear, story-based, text-dependent, simple to interact with) which make it difficult to compare to other genres, such as those involving multiple players, strategic, or with open-ended outcomes. Thus, our knowledge of gamified climate change engagement will continue to advance through the accumulation of complementary evidence.

Fifth, the experiment was designed using only a non-game condition and two 3D environment-based versions of the same game. In the future additional conditions, such as a text-based game closer to the control condition, could be added as intermediate steps of gamified learning.

Finally, and based on the above discussion points, our sample largely consisted of highly educated young and middle-aged adults, many of which may have found the knowledge test relatively easy, or the content of the intervention already known to an extent. This may have limited the potential for knowledge acquisition. Thus, we propose that future studies use similar applications either with more difficult content or involving audiences with a lesser degree of formal education, children, and elderly people, in addition to those who may be skeptical about climate change in some way, from its causes to the severity of its consequences and its proposed mitigating measures. Some audiences, such as the elderly, may also find usability issues with immersive VR.

6 CONCLUSION

This study has examined and compared the learning potential of text- and game-based communication of climate change information. The study consisted of an experiment involving N=105 participants randomly assigned to three groups, where they were exposed to a text illustrated with charts, a screen-based PC game, and an immersive VR version of the same game. The results of a pre- and post-test questionnaire suggest that all three media resulted in learning, although there were no significant differences in improvement between the three groups. A close examination of the data also revealed how aspects of the game may have led to various forms of learning, and we derived recommendations for future design and research. These results provide insights into the potential of game-based learning for climate change engagement, especially when the goal is to acquire basic knowledge using single-player narrative games, and its comparison with more traditional forms of instruction. Given the potential for more questions to be answered, this study is a first exploratory comparison of the potential of text and digital games, both on traditional screen and in immersive VR, for climate change engagement. In the future, more data can be leveraged to continue investigating this space, including the examination of possible moderators such as demographic factors and worldviews; mediators such as enjoyment and gameful experience; and outcomes including systems knowledge, attitudes, intentions, and behavior, both quantitative and qualitatively.

7 DATA AVAILABILITY STATEMENT

The questionnaire used in the experiment and the anonymized answer data are available as an artifact [28].

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Text- and game-based communication for climate change attitude, self-efficacy, and behavior: A controlled experiment

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Text- and game-based communication for climate change attitude, self-efficacy, and behavior: A controlled experiment

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ABSTRACT

The advantages of both gamification and immersive technologies are often advocated for in contexts in which human motivation is lacking. This is the case with environmental sustainability and climate change engagement, where knowledge alone is not sufficient for pro-environmental behavior. However, the existing literature lacks rigorous studies comparing games and immersive media to more traditional communication methods. In this article, we describe an experiment (N=105) where participants used a climate change game in PC or immersive VR or were assigned to a text-based control. Our findings suggest that all three conditions increased climate change attitudes and environmental self-efficacy, but no significant differences were found between them. Although VR players tended to enjoy their experience significantly more than other participants, we did not find significant differences in self-reported immersion. Furthermore, neither enjoyment nor immersion correlated with attitude or self-efficacy shifts. Our exploration of participant behavior yielded similar results for all three conditions, both in commitment to action and self-reported completion ten days after the intervention. Our results suggest that games can improve attitudes and self-efficacy even in highly involved audiences, but their comparative advantage in certain contexts may be smaller than commonly assumed.

1. Introduction

As the climate crisis seriously threatens ecologic, economic, societal and cultural systems, urgent action towards reducing greenhouse gas emissions and coping with its impacts in the near-term is fundamental (Intergovernmental Panel on Climate Change, 2022). Over two decades of research on climate change engagement have yielded numerous insights on how people connect with the issue (Kollmuss & Agyeman, 2002; Lorenzoni, Nicholson-Cole, & Whitmarsh, 2007; Whitmarsh, Lorenzoni, & O'Neill, 2012) and multiple suggestions on how to increase engagement and support those who are already engaged (Wibeck, 2014). These include interactive visualizations (Moser, 2010; Sheppard, 2012; Wibeck, Neset, & Linnér, 2013) and, more broadly, experiential environments where people can make sense of the issue and their own position towards it Monroe, Plate, Oxarart, Bowers, and Chaves (2019).

Gamification, or the transformation of activities to afford game experiences (Hamari, 2019), is one of such proposed methods, and has been generally successful in promoting cognitive, affective, and behavioral engagement with climate change (Fernández Galeote et al., 2021). Given that gamification often refers to the application of game design elements in non-game contexts (Deterding, Dixon, Khaled, & Nacke, 2011) as opposed to full-fledged serious games, we clarify that in this study it is used as an umbrella term for any form of gameful engagement that seeks outcomes beyond entertainment, including serious games and game-based learning (Hamari, 2019). This use of the word has been adopted in recent climate change engagement literature (Douglas & Brauer, 2021; Fernández Galeote et al., 2021; Rajanen & Rajanen, 2019) and beyond (Koivisto & Hamari, 2019; Krath, Schürmann, & Von Korflesch, 2021) and points towards the importance of exploring different artifact configurations as part of an overarching phenomenon.

When applying gamification, motivation to engage with contents and enact behaviors (Plass, Homer, & Kinzer, 2015; Ryan, Rigby, & Przybylski, 2006) is typically sought through virtual game worlds that encourage direct experience and exploration as memorable ways of engaging with a topic (Monroe et al., 2019; Plass et al., 2015) as well as stories, lived events and characters that tend to elicit enjoyment and emotional engagement (Hemenover & Bowman, 2018; Plass et al., 2015). Another promising avenue is immersive virtual reality (VR), which is not only typically engaging (Pellas, Dengel, & Christopoulos, 2020) but also allows users to feel a sense of presence, or being in the virtual environment (Cummings & Bailenson, 2016). In this way, climate change can become immediate and concrete rather than remote and intangible (Breves & Schramm, 2021; Markowitz, Laha, Perone,

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Pea, & Bailenson, 2018), and thus more emotionally salient (Markowitz & Bailenson, 2021).

However, the existing literature on gamified and game-based climate change engagement lacks various important research avenues, including the use of potentially effective communication frames, the examination of immersive VR games, a focus on engagement aspects besides knowledge, and the use of rigorous experimental designs comparing the effects of games to informationally equivalent conditions, for example texts (Fernández Galeote et al., 2021). Similarly, the literature on immersive environmental persuasion typically focuses on non-interactive conditions, such as 360-degree videos, and lacks empirical evidence of effectiveness (Breves & Greussing, 2021). Therefore, and despite the generally positive results associated with these media and technologies (Breves & Greussing, 2021; Fernández Galeote et al., 2021), our knowledge remains fragmented and its empirical support limited, especially when comparing games and immersive technologies to other forms of communication.

Contributing to address the aforementioned gaps, this article describes an experiment (N = 105) involving a narrative climate change game that frames climate change as a wellbeing issue and involves its anthropic causes, mechanisms, and consequences for non-human and human life, especially infectious diseases and pandemics. Participants either played the game on a computer screen or immersive VR, or were assigned to a text-based informational equivalent acting as a control condition. Our study examines the effects of playing the game or reading the text on climate change attitude, environmental self-efficacy, and pro-environmental intentions (PEI) and behaviors (PEB). Our findings suggest that games on traditional screens and immersive VR can be as effective as text-based communication methods in promoting these aspects of engagement, thus complementing previous findings involving similar comparisons using games (Soekarjo, van Oostendorp, et al., 2015) and extending them into the area of interactive immersive VR.

2. Background

2.1. Enjoyment as part of the game experience

This study concerns gamification understood as the result of transforming an activity to afford a game-like experience with the intention to bring a change, be it cognitive or behavioral, through discrete game elements or full-fledged games (Hamari, 2019). Game experiences typically include outcomes such as enjoyment, which can be seen as the satisfactory feeling associated with a positive experience (Cairns, Cox, & Nordin, 2014).

Thus, the first two hypotheses refer to the potential of game-based communication in VR and PC to elicit interest and enjoyment. Educational games have been found to be more engaging than comparable texts (Arici, 2008) and other learning methods (Lieberoth, 2015), in some cases with large effect sizes (McLaren, Adams, Mayer, & Forlizzi, 2017). Gamification is supported by theories that assume positive states such as flow and intrinsic motivation as part of the core experience of playing (Krath et al., 2021). This leads us to hypothesize:

- H1.1: Playing the game in any form will be significantly more enjoyable than reading the text.

In addition, immersive VR has been perceived as more enjoyable than screen-based media (Makransky, Andreasen, Baceviciute, & Mayer, 2021; Makransky & Mayer, 2022; Pellas et al., 2020; Reer, Wehden, Janzik, Tang, & Quandt, 2022). This is not surprising since new and complex experiences tend to elicit curiosity (Berlyne, 1954). Similarly, a "novelty effect" has been reported in gamification (Hamari, Koivisto, & Sarsa, 2014). Therefore, we hypothesize:

- H1.2: Playing the game in VR will be more significantly enjoyable than playing on PC.

2.2. Immersion as part of the game experience

Immersion is also typically seen as part of the game experience. This is a concept used in game studies to refer to the emotional and attention involvement experienced when doing an activity (Cairns et al., 2014) and which can occur via challenges, imagination (which would make a text potentially immersive), and sensory aspects (Ermi & Mäyrä, 2007).

Our next hypothesis refers to the immersive qualities of the treatment conditions. This study focuses on immersion as a construct that signals involvement with the game rather than spatial presence, or the feeling of being transported to a different space (Cairns et al., 2014). However, presence has similarities with sensory immersion (Ermi & Mäyrä, 2007) and the technological immersiveness of a medium typically has a considerable effect on the sense of presence (Cummings & Bailenson, 2016). Technological immersiveness refers to a technology's capacity to present the user with a vivid virtual environment while isolating them from their surroundings; thus, technologies capable of offering multisensory and high fidelity simulations, a correspondence between physical and virtual body action, and narratives that transport the user away from their physical surroundings are more immersive than those not including these aspects (Slater & Wilbur, 1997). Consequently, a simulation in immersive VR is more technologically immersive than a simulation on a PC screen, which is more immersive than a text-based description of the simulation. In addition, the evidence reported by meta-reviews (Cummings & Bailenson, 2016) and individual studies tends to show higher presence in VR than in 2D screen (Shu, Huang, Chang, & Chen, 2019; Wagler & Hanus, 2018), although it must be noted that presence has a personal component, or immersive tendency, which may be affected by other psychological variables (Weibel, Wissmath, & Mast, 2010).

In addition to sensory immersion, games may also increase immersion by providing challenges, which our text-based control does not include (Ermi & Mäyrä, 2007). Therefore, it is hypothesized that participants will report higher levels of immersion in the game conditions, and in VR in particular due to its higher potential for cognitive absorption (Kampling, 2018), even comparable to that of real-world activities (Lui & Goel, 2022). Thus, we hypothesize:

- H2: Technological immersiveness will be positively associated with self-reported immersion.

2.3. Climate change attitude

Climate change engagement involves three forms of connection to the issue: cognitive (knowing), affective (caring), and behavioral (acting) (Lorenzoni et al., 2007). Rather than being limited to awareness and knowledge, engagement considers the internal and external factors, from attitudes to economic constraints and social norms, that influence a person's relationship to climate change (Gifford & Nilsson, 2014; Lorenzoni et al., 2007; Whitmarsh et al., 2012).

During the last two decades, the complexity of climate change engagement has been explored leading to significant advances in its scientific understanding and promotion (see, e.g., Gifford & Nilsson, 2014; Kollmuss & Agyeman, 2002; Lertzman, 2019; Lorenzoni et al., 2007; Whitmarsh et al., 2012). Suggested support methods include the use of specific message frames (Badullovich, Grant, & Colvin, 2020), digital visualizations (Moser, 2010; Sheppard, 2012; Wibeck et al., 2013), interactive environments (Monroe et al., 2019; Sterman, 2011; Wibeck, 2014), and dialogic processes (Moser, 2010; Wibeck, 2014), all of which point to the potential of gamification as an experiential method.

Multiple variables have been included in pro-environmental behavior models, including awareness of consequences, responsibility, personal norms (Schwartz, 1977), values, beliefs in threats and possibility for restorative action (Stern, Dietz, Abel, Guagnano, & Kalof, 1999), personality traits, social and cultural factors, and other conditions (Kollmuss & Agyeman, 2002). This study examines climate change attitude as an important precedent to PEI and PEB (Ajzen, 1991; Casaló & Escario, 2018; Klöckner, 2013). Attitude can be defined as a combination of beliefs, affect, and intentions towards an activity or issue (Schultz et al., 2005).

In this vein, our third set of hypotheses considers the role of the intervention on climate change attitude. A meta-review has shown that interventions targeting climate change attitudes amount to a small positive effect irrespective of the type of intervention (Rode et al., 2021). Indeed, persuasive texts can have an attitudinal effect on climate change (Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2012), as can game-based interventions in various formats (Fernández Galeote et al., 2021). Therefore, we hypothesize:

- H3.1: The intervention in any of its forms will positively affect participants' climate change attitude.

The existing theoretical bases support the notion that games and gamification may lead to heightened attitudinal effects when compared to less immersive or interactive media (Janakiraman, Watson, & Watson, 2018), as could immersive VR (Breves & Greussing, 2021). However, a dearth of comparisons between games and more traditional media in the area of climate change engagement has been observed (Fernández Galeote et al., 2021), and in particular in respect to attitudes (Soekarjo et al., 2015). A similar issue exists in the lack of robust empirical designs in gamified sustainability education research (Hallinger, Wang, Chatpinyakoop, Nguyen, & Nguyen, 2020) and in regards to empirical evidence of VR's effectiveness in shifting environmental attitudes (Breves & Greussing, 2021). When comparing a computer game about climate change to a control condition involving the same information in text and image, no significant differences were found (Soekarjo et al., 2015). Similarly, a comparison of VR- and non-VR-based conditions depicting the effects of climate change on a glacier saw an increase in awareness across conditions, but found no differences between the two (Thoma et al., 2023).

Despite these shortcomings, studies in other areas have found that both screen and immersive VR stimuli impacted attitudes (Bujić, Salminen, Macey, & Hamari, 2020) and immersive VR videos were more effective than regular screen ones (Breves & Heber, 2020; Filter, Eckes, Fiebelkorn, & Büssing, 2020; Fonseca & Kraus, 2016). Technological advances such as immersive VR have been key in the emotional turn in journalism, which has clear attitudinal implications as it refers to new forms of emotion-driven reporting seeking to create closer and trusting relationships with audiences (Lecheler, 2020; Sánchez Laws, 2020). Closer to climate change, the study comparing depictions of climate change effects on a glacier found a significant increase in environmental awareness for the VR but not for the non-VR conditions, despite the lack of significant difference between the two (Thoma et al., 2023). In another study, VR embodiment of animals resulted in larger connectedness to nature than watching a video (Ahn et al., 2016). In other cases, the level of interactivity has been linked to shifts in attitudes (Sundar, Kalyanaraman, & Brown, 2003). It has also been found that games can raise more interest in climate change issues than a similar website (Nussbaum et al., 2015). We hypothesize:

- H3.2: The game-based conditions will result in a larger climate change attitude shift than reading the text.
- H3.3: Technological immersiveness will be positively associated with a shift in climate change attitude.

In relation to the above, self-reported immersion could be expected to relate to climate change attitude. Previous studies have observed correlations between screen-based and immersive VR video and human rights attitudes (Bujić et al., 2020) or theorized that narrative immersion can lead to belief in content and attitudinal effects (Green, 2021). In terms of environmental attitudes, higher reported levels of presence have been linked to more concern for the environment (Markowitz et al., 2018) and environmental awareness (Thoma et al., 2023), and vividness of stimulus has been linked to pro-environmental behavior (Bailey et al., 2015). More broadly, studies on the effect of VR on attitudes and behavior report generally positive findings, which is commonly explained theoretically through spatial presence and embodiment (Breves & Greussing, 2021). However, these studies either focus on different areas of study or involve designs that are quite different to ours, with considerable importance of player avatars. We also hypothesize:

- H3.4: Self-reported immersion will be positively associated with a shift in climate change attitude.

2.4. Environmental self-efficacy

Environmental self-efficacy is another important antecedent to PEI and PEB (Ajzen, 1991; Casaló & Escario, 2018; Klöckner, 2013). Self-efficacy, which refers to a person's confidence in their capacity to overcome difficulties in acting (Moeller & Stahlmann, 2019), is studied in our final set of hypotheses. The proposed intervention is not a simulation of behavior where people directly practice detailed PEBs. Rather, it is mostly based on simple actions, verbal argumentation and suggestive imagery. However, apart from mastery experiences and vicarious learning, people can develop self-efficacy through social persuasion and physiological and affective states (Lehikko, 2021). By providing support against amotivation (Pelletier, Dion, Tuson, & Green-Demers, 1999) and showing actions that can help mitigate climate change, all three conditions attempt to promote both information acquisition and emotional states conducive to action, from concern to anticipated positivity. As interventions based on knowledge transmission have increased efficacy beliefs (Geiger, Swim, & Fraser, 2017), and previous interventions have shown that both immersive VR and text can increase people's beliefs in their own capacity to affect the environment (Ahn, Bailenson, & Park, 2014), we hypothesize:

- H4.1: The intervention in any of its forms will positively affect participants' environmental self-efficacy.

Further, and despite the aforementioned lack of comparisons between games and equivalent informational content, as well as a lack of research of game-based climate change engagement in VR (Fernández Galeote et al., 2021), studies involving PC and VR-based educational training tend to report heightened self-efficacy (Lehikko, 2021). In stimuli related to environmental topics, immersive virtual environments have been found to improve internal environmental locus of control compared to video and text, an effect that may be attributed to perceptual richness and interaction (Ahn et al., 2014). Training specific behaviors in VR has been found to lead to more self-efficacy than video (Liu, Fan, Liu, & Ye, 2022) and traditional lecturing (Francis, Bernard, Nowak, Daniel, & Bernard, 2020). VR-based English learning has been deemed more self-efficacy conducive than traditional methods (Zheng, Young, Brewer, & Wagner, 2009). Research has qualitatively associated the gains in self-efficacy with the fact that VR affords hands-on experience and feedback for specific behaviors (Petersen, Klingenberg, Mayer, & Makransky, 2020). More broadly, virtual environment-based treatments, whether immersive or not, have been shown to lead to higher self-efficacy when compared to a control group that did not play and only completed a survey twice (Shu et al., 2019). However, it must be taken into account that the game treatments do not offer particular skills to be practiced and repeated towards mastery. Despite this difference, we hypothesize:

- H4.2: The game-based conditions will result in a larger environmental self-efficacy shift than reading the text.

We are also interested in observing relationships between immersion and self-efficacy. Previous research has provided qualitative evidence that behaviors are mimicked more easily with VR controllers than with a mouse, which aids behavior memorization (Shu et al., 2019). Another study found that a feeling of presence was one of the mediators between usability and self-efficacy in a VR crane operating training system (Song, Kim, Kim, Ahn, & Kang, 2021). Avatar use has also been linked to increased nutrition efficacy via self-presence (Behm-Morawitz, Lewallen, & Choi, 2016). While these studies speak of the possible relationships between immersion/presence and self-efficacy in various areas, they tend to focus on the embodied practice of specific behaviors, which our design does not prioritize, or identification with an avatar separate from the player's identity, which is not the case either. While acknowledging these caveats, based on the evidence above we propose the hypothesis:

- H4.3: Self-reported immersion will be positively associated with a shift in environmental self-efficacy.

2.5. Exploring attitudes and self-efficacy in relation to enjoyment

In addition to the above hypotheses, we aim to explore the participants' self-reported climate change attitude and environmental self-efficacy shifts in relation to their interest/enjoyment. While links have been established between intrinsic motivation and pro-environmental behavior in daily life (Cooke, Fielding, & Louis, 2016; Pelletier, Tuson, Green-Demers, Noels, & Beaton, 1998), we seek to examine the specific space comprising enjoyment with a single, brief activity and reported changes in attitude as a result of participating. Given that attentional and perceptual biases exist in climate change engagement (Luo & Zhao, 2021), an enjoyable activity could reduce the person's predisposition to shape attention based on their pre-existing beliefs and motivations. In addition, a heightened motivation to play climate change games could influence motivation towards the climate through a recursive relationship (Vallerand, 1997). However, these possibilities remain only theoretical.

Regarding environmental self-efficacy, environmental amotivation due to a lack of competence has been correlated with negative feelings, and competence associated with motivation (Pelletier et al., 1999) and thus likely with positive affect. Interventions causing various emotions have been linked to pro-environmental action (Brosch, 2021), and positive affect in particular can be understood as a possible antecedent of climate change behavioral engagement when experienced or anticipated positive emotions are activated (Schneider, Zaval, & Markowitz, 2021). However, here we are interested in examining enjoyment from gameplay, rather than that from pro-environmental actions.

Thus, considering a lack of strong theoretical or empirical references apt to our intervention in the relationships signaled above, our first research question is:

- RQ1: How are the climate change attitudes and environmental self-efficacy data distributed in terms of interest/enjoyment?

2.6. Exploring pro-environmental intentions and behaviors

Finally, we are interested in engaging in a first exploration of the behavioral implications of our intervention. The relationship between pro-environmental intentions/behaviors and immersive/interactive experiences has been explored in the past (Ahn et al., 2014; Ahn, Fox, Dale, & Avant, 2015; Oh, Sudarshan, Jin, Nah, & Yu, 2020), generally in favor of the more immersive and interactive conditions. The role of attitudes and self-efficacy as predictors of PEI has been established in the literature, as well as the role of PEI in influencing PEB (Ajzen, 1991; Ajzen & Fishbein, 1980). In our intervention, all conditions involve a form of verbal commitment prior to the opportunity to engage in a particular PEB, which is a potentially equalizing factor as a predictor of PEB (Hines, Hungerford, & Tomera, 1987). Therefore, our second research question is:

- RQ2: What PEIs and PEBs can be observed as a result of the intervention?

3. Methods

3.1. Experiment design and participants

For this study, we conducted a lab experiment where participants were randomly allocated to three groups: a text-based stimulus (hereafter, control), a desktop screen-based 3D game (hereafter, PC), and an immersive VR version of the same game (hereafter, VR), while minding the gender distribution across groups as a potentially relevant variable for climate change engagement (Bloodhart & Swim, 2020; Gifford & Nilsson, 2014). The study follows the guidelines of the Finnish National Board on Research Integrity (TENK) and received the approval of Tampere University's Data Protection Officer.

Like previous literature involving the effects of immersive media, we are interested in medium-to-large effect sizes (see Breves & Schramm, 2021); that is, effect sizes approximately equal to or larger than Cohen's $d = 0.5$, or a difference of half a standard deviation (Cohen, 1988). According to a power analysis performed in Jamovi jpower, a one-tailed paired samples t-test would require a total sample size of 27 to reliably (with a power of 0.80) detect a minimum effect size of 0.5 with a maximum alpha of 0.05, which our sample ($N = 105$, with 35 participants per group) exceeds. Our sample size was constrained by the financial, time, and human resources available as well, so we aimed to recruit the largest possible sample given the desired statistical power.

The final sample was $N = 105$ participants (control $n = 35$; PC $n = 35$, VR $n = 35$). The average age (control = 29.29; PC = 28.57; VR = 30.63) and gender distribution (control: Female = 20, Male = 14, Other = 1; PC: F = 20, M = 14, O = 1; VR: F = 21, M = 13, O = 1) were similar in all three conditions. Most participants had attained some degree of university education (university of applied sciences bachelor's degree ($n = 14$), university of applied sciences master's degree ($n = 2$), university bachelor's degree ($n = 27$), and university master's degree ($n = 48$)), while a minority had primary education ($n = 1$), vocational school or course ($n = 2$), general upper secondary education (matriculation examination) ($n = 10$), or vocational college (post-secondary) ($n = 1$) education. The participants' origins included Finland ($n = 35$), Asia ($n = 24$), the EU ($n = 23$), the US or Canada ($n = 5$), non-EU Europe ($n = 4$), Africa ($n = 3$), Middle East ($n = 3$), and Latin America ($n = 2$). Six participants came from other areas, excluding Oceania.

3.2. Materials

3.2.1. Stimuli

This study uses a multi-platform (PC and VR) game designed and developed by the first author using the Unity game engine (version 2020.3.19f1)—*Climate Connected: Outbreak*. The game is single-player and story-based, meaning that the content is presented to all players in a similar order. The game frames climate change as a wellbeing issue by connecting its causes, physical mechanisms, and consequences to non-human and human life, with a focus on infectious diseases and pandemics.

Climate Connected: Outbreak can be described as a serious game since it consists of a system aiming to elicit engagement to produce outcomes beyond entertainment, but it also seeks to directly gamify participant behavior after playing through an email with climate action ideas, which will be described in the next subsection. Every step of the design process considered that the game would be multi-platform and used in research, and thus both versions needed to be as comparable as possible. Once development using the game engine began, the VR version was the first one to be implemented, given that its affordances are less conventional and we aimed to use the capabilities of the hardware while not introducing methods of interaction that would be trivial to implement and experience on PC but inadequate for VR.

In the game, players engage in three main forms of interaction. First, they can select dialog options when they encounter text-based

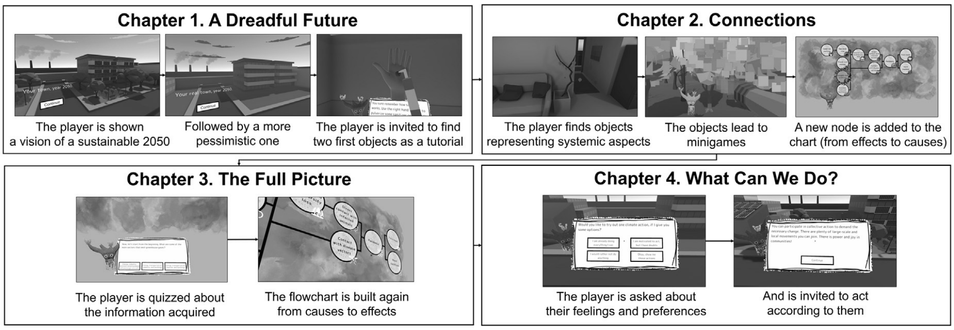

Fig. 1. The game's four chapters, including major events and actions within them.

information and prompts; therefore, they are able to progress through the explanations at their own pace, and occasionally select one of various choices leading to different feedback. Second, move through 3D spaces using a teleporting system. Third, select, grab, and throw objects in the space. The PC version is entirely mouse-based, where mouse movement rotates the camera and the left mouse button performs all actions described above. Meanwhile, the VR version requires pointing a controller at the element to be interacted with and pressing a trigger. While both systems are simple to use, VR permits a more physically involving interaction—where object manipulation is needed, VR players physically point their controller and hold the trigger to grab and need to move their arm and release the trigger to throw. The forms of interaction described for both systems should be rather natural to those less familiar with digital games or immersive VR, while the use of either controller in VR considers both right- and left-handed players. Finally, the choice of a teleporting-based locomotion system should minimize motion sickness.

The content is presented through four chapters. First, players find 14 items that represent elements of the climate-wellbeing system presented. The system is shown as a flowchart that players complete one node at a time—first finding a relevant object, then playing an associated minigame, and finally seeing how the new concept fits within the structure. The minigames are described, in order and with their associated node, in Table 1. After these, players complete a quiz reviewing the content and are invited to act for the climate if they wish to do so. For an overview of the game's structure, see Fig. 1. A video with more information has also been provided as supplementary content.

As elements potentially relevant to attitude, self-efficacy and behavior, the game includes (a) a guiding character that provides information and encourages players to explore the game and connect the game's insights to their own life and experiences; (b) textual, visual and interactive depictions of climate change-relevant aspects centering the player and the fictional local space, presented following climate change communication best practices (Sheppard, 2012; Wibeck, 2014); (c) motivational support adapted to the player's self-reported views (Roser-Renouf, Stenhouse, Rolfe-Redding, Maibach, & Leiserowitz, 2015) and based on self-determination theory (Cooke et al., 2016) and environmental amotivation-countering principles (Pelletier et al., 1999); and (d) proposed action profiles to act in the real world, thus going beyond consumer behavior (Stern, 2000; Wibeck, 2014). The behavior options are described at the end of Section 3.2.2.

As a control condition, participants were presented with a document that includes the same textual information, a series of flowcharts which also feature in the game, and narrative descriptions of the content encountered in the game.

3.2.2. Measurement instruments

Existing questionnaires were used to measure the participants' level of interest and enjoyment in the experience, as well as their immersion level, after the treatment. We also used existing instruments to measure climate change attitude and self-efficacy before and after the treatment. Additional PEI and PEB data were sourced from custom questionnaires.

Interest and enjoyment in the experience were measured via the Intrinsic Motivation Inventory's Interest/Enjoyment subscale (Center for Self-Determination Theory, n.d.) (hereafter ENJOYMENT), which consists of seven items presented in random order and rated on a 7-point Likert scale. The Cronbach's alpha value for the ENJOYMENT responses was 0.906, which denotes an excellent internal consistency. The data were computed as an average per participant.

Immersion was measured using the IMMERSION subscale in the GAMEFULQUEST instrument (Högberg, Hamari, & Wästlund, 2019), which aims to measure immersion in line with the interpretation presented in the background (Cairns et al., 2014). The Cronbach's alpha value for the IMMERSION responses was 0.714, which denotes an acceptable internal consistency. The data were computed as an average per participant.

To measure the participants' climate change attitude, we used the Climate Change Attitude Survey (CCAS), which was created to measure middle school "students' beliefs and intentions toward the environment with a focus on climate change" (Christensen & Knezek, 2015, p. 773) but has since been used with other samples, such as pre-service teachers (Oladipo, Awofala, & Osokoya, 2020). As previous studies have only arrived at tentative factors (Christensen & Knezek, 2015; Oladipo et al., 2020), we performed an exploratory factor analysis (EFA) on the pre-intervention participant responses using Jamovi 2.3.21.0 (package jmv 2.3.1). Bartlett's Test of Sphericity was adequate (<.001), and KMO measures of sampling adequacy showed most items to be adequate (0.8–1.0) and three to be middling (0.7–0.79), including Q10 (0.773), Q11 (0.792), and Q15 (0.775) (Kaiser, 1974).

The method involved minimum residuals and oblimin rotation, since it is a non-orthogonal option adequate for the assumption that the two subscales are correlated, as is the case. Parallel analysis detected a best fit with three factors. However, model fit measures reported unacceptable values (RMSEA 0.094, TLI 0.850) according to the literature (Hu & Bentler, 1999). Although it has been recommended not to use model fit indices in EFA due to their excessive sensitivity (Montoya & Edwards, 2021), the use of cutoff values questioned (Xia & Yang, 2019), and best practices suggesting that parallel analysis provides the largest number of plausible factors (Watkins, 2018), we first explored larger model configurations under the assumption that smaller RMSEA and larger TLI values indicate better fit (Xia & Yang, 2019). While models with 4 and 5 factors offered better fit according to these measures,

Table 1
The minigames in the order in which players encounter them; that is, from consequences to causes of climate change. Each minigame has an associated node, which are organized here according to more abstract categories. Interactions in the minigames are complemented with text explanations related to the issue being represented.

Category	Node	Minigame
Pandemic consequences	Face mask	The player is given a hand sanitizer bottle, which they must spray and spread on their hands. This minigame is part of the tutorial-like introductory chapter.
	Hand hygiene	The player is given a box of masks and they must throw them o approaching figures to prevent contagion. This minigame is part of the introductory chapter.
Climate change impacts on life	Direct contact with infected animals	The player embodies a bird pursued by a red cloud representing environmental degradation. Every time the player moves, the cloud extends. As the cloud spreads, the only option left is to migrate to the city.
	Contact with disease vectors	The player must place a mosquito net over a door before the time limit, applying glue first and then affixing the net to the frame. If they fail, the mosquitoes arrive with the nighttime and they must repeat the process.
	Habitat and biodiversity loss	The player is shown a forested area crossed by a river, and encouraged to build on it. As they select each segment, the forest gets cleared for construction and a river mammal's death is revealed as a consequence.
Physical manifestations of climate change	Droughts and wildfires	The player is surrounded by trees on fire which they can extinguish using a water hose that they have equipped, but no matter how fast they stop the fire, the trees cannot be saved.
	Extreme heat and heatwaves	The player is in the street during a scorching heatwave, represented by an orange hue covering everything and dead birds at different spots. The player must find the only safe place, a garage with air conditioning.
	Floods and storms	The player is in the middle of a flooded area. Since the stagnant water, reeds and accumulated leaves have allowed mosquitoes to breed in various places, they must find and remove such places.
	Land ice melting & Sea level rise	At the seafront of a town, facing the ocean and some distant ice formations, the player witnesses how sea level has risen in the past century and is forecasted to rise in the coming century, including the possibility of rise that submerges part of the surrounding town and surfaces multiple dead fishes around them due to warming.
Causes of climate change	Buildings	The player turns on water heating to prepare a hot bath, but this makes a fossil-based power plant appear behind as the infrastructure heating the water. They also turn on an air conditioning unit, which is revealed to emit potent greenhouse gases. The player turns them off before ending the minigame.
	Land use	The player is in a farm. With a water hose, they water some cereal crops, but when they have grown they are eaten by a cow, signifying the extensive use of cereals to feed animals. Then, as climate change progresses, the yield becomes smaller, but the animal keeps eating it. In the end, the player closes the barn doors representing the reduction of cattle farming to promote food security.
	Industry	The player is tasked with packing plastic toys. After this, a more pro-environmental option is presented, a toy made of wood, combined with the reduction in consumption.
	Energy	First, the player plays a shooting game in which each shot increases their "CO2 score", pointing towards the relationship between electronics and energy use. After this, they must disconnect the power going from a fossil fuel power plant and switch the energy source to wind turbines instead.
	Transport	The player sees the number of airplane tickets and soft drinks bought per second. Then, they can throw a hammer at the screen to represent a break with consumerism associated with, e.g., certain types of tourism.

we did not consider them to offer stronger theoretical explanations, as the variables seemed to refer to either (a) beliefs in climate change and its severity, or (b) attitudes regarding climate action, which are similar to the instrument's original theoretical foundations being beliefs and intentions (Christensen & Knezek, 2015). Thus, these models were discarded.

In the opposite direction, parallel analysis suggested one factor that was loaded by only two variables, which is a symptom of overfactoring (Gorsuch, 1983, cited in Watkins, 2018), with a third variable saliently loading (i.e., with a pattern coefficient $\geq .3$) on two different factors, which is also indicative of a sub-optimal solution (Watkins, 2018). We also used a scree plot as a subjective adjunct to the parallel analysis estimate (Watkins, 2018), which seemed to indicate a best fit with two factors, after which the magnitude change of the component eigenvalues was markedly reduced.

Given these procedures, which problematized solutions with three or more factors while pointing at two different theoretically justifiable constructs, we present here the two-factor model. Whereas factor 1 (climate change beliefs, CCBEL) seems to involve beliefs that climate change is real, concerning, and something that should be known and acted upon, factor 2 (attitudes towards individual climate action, CACT) focuses on attitudes towards the actions of individuals (often presented as I/we statements), which may also point towards intention to act as a component of attitude (Schultz et al., 2005) (see Table 2).

The Cronbach's alpha values were satisfactory for all six datasets involved in the analyses (CCAS pre = 0.868, post = 0.861; CCBEL pre = 0.869, post = 0.886; CACT pre = 0.781, post = 0.729). The values for the overall CCAS scale, CCBEL and CACT were computed both as average values for each participant before and after the intervention, and as a single score reflecting change between pre and post (post–pre).

To measure the participants' environmental self-efficacy (ESE), we used the 10-item version of the Environmental Self-Efficacy Scale (ESE-10) (Moeller & Stahlmann, 2019). The instrument asks respondents to rate a series of pro-environmental behaviors on a scale of zero to ten based on how certain they are that they are capable of doing them regularly. The Cronbach's alpha values were satisfactory for the pre (0.914) and post (0.880) values. The results were computed as averages and as a score reflecting change between pre and post.

To measure willingness to engage in climate action, participants were asked whether they wanted to select an area of climate action of interest to receive an email with a series of actions that they could do. Participants in the PC and VR conditions encountered this at the end

Table 2
EFA results on the pre-treatment CCAS scale.

Item	Descriptive statistics				Factors		h^2
	Mean	SD	Skewness	Kurtosis	CCBEL	CACT	
1. I believe our climate is changing	4.76	0.53	−2.58	7.85	**0.77**	−0.13	0.54
2. I am concerned about global climate change	4.55	0.73	−1.90	3.69	**0.76**	0.03	0.59
3. I believe there is evidence of global climate change	4.78	0.48	−2.14	3.95	**0.88**	−0.04	0.76
4. Global climate change will impact our environment in the next 10 years	4.65	0.71	−2.54	7.84	**0.73**	0.08	0.58
5. Global climate change will impact future generations	4.87	0.39	−3.10	9.59	**0.70**	−0.01	0.49
6. The actions of individuals can make a positive difference in global climate change	4.13	0.99	−1.06	0.39	0.19	**0.65**	0.55
7. Human activities cause global climate change	4.69	0.52	−1.41	1.07	**0.67**	0.10	0.51
8. Climate change has a negative effect on our lives	4.54	0.81	−1.97	3.98	**0.65**	0.03	0.44
9. We cannot do anything to stop global climate change (R)	4.29	0.91	−1.47	2.33	0.20	**0.45**	0.30
10. I can do my part to make the world a better place for future generations	4.25	0.72	−1.20	3.4	0.26	**0.36**	0.26
11. Knowing about environmental problems and issues is important to me	4.31	0.80	−1.44	2.84	**0.34**	0.23	0.23
12. I think most of the concerns about environmental problems have been exaggerated (R)	4.46	0.75	−1.40	1.74	**0.52**	−0.02	0.26
13. Things I do have no effect on the quality of the environment (R)	3.87	0.91	−0.59	0.04	0.11	**0.61**	0.43
14. It is a waste of time to work to solve environmental problems (R)	4.7	0.61	−2.90	12.7	**0.45**	0.13	0.27
15. There is not much I can do that will help solve environmental problems (R)	3.83	1.07	−0.80	−0.03	−0.12	**0.90**	0.74

Note. R = reversed item. h^2 = communality. Salient pattern coefficients ≥.3 in boldface.

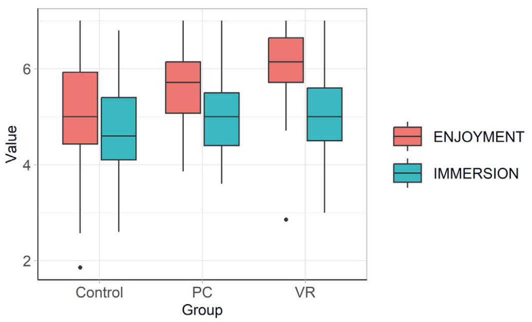

Fig. 2. ENJOYMENT and IMMERSION scores among the three participant groups.

of the game, whereas the control included this as an optional questionnaire after reading the text. The six options include advocate (be vocal and spread awareness), artist (create based on knowledge, feelings and perceptions of climate change), conscious citizen (do low-commitment political action), lone rider (take individual action), scholar (get to know more), and team player (support or engage in collective action), plus a refusal to engage. The participants' choice was recorded and they received an email with suggestions in accordance with it. For game players, the email was written from the perspective of the game's guiding character, and included a badge-like image reflecting their choice; text readers received only a text email written from the perspective of the research team. Finally, ten days after participating, they received a final survey with questions about their chosen action, including whether it had been done, and if it had inspired further action. The final email was also written from a different perspective depending on the participant's assigned condition.

3.3. Procedure

The study was advertised as an "experiment about immersion in climate change information" and compensated with one cinema ticket for participating. The experiment communication materials included a link to the initial survey, where prospective participants gave their informed consent and answered the pre-treatment questionnaire. Then, they booked a time for the experiment. They were told in advance to not wear glasses if possible, since VR may be used. Once they arrived at the experiment site, located in Tampere University, they were briefed on the process and invited to engage in a cognitive task related to climate change. Next, they completed a knowledge test and started the treatment itself. The participants were given the goal of getting "as good an understanding as possible of the content of the game/text". Both the control and PC conditions took place in the same computers where the test had been answered, located in individual cubicles with no outside view and soundproofing. The VR condition took place in a separate area that provided enough space for participants to move and employed an Oculus Quest 2 headset with two standard controllers. Participants were given a time frame of 30 to 60 min to finish the game or text and were informed that if they reached 60 min they would be invited to finish as soon as possible. Text readers who finished earlier than 30 min were allowed to re-read freely until the minimum time had been reached. After the treatment was completed, the participants immediately answered the post-treatment survey before moving on to other tasks, which included a second part to their cognitive exercise and knowledge test, and an optional interview.

4. Results

4.1. Enjoyment

First, we aimed to compare between the three groups to see whether playing the game led to higher ENJOYMENT than reading the text (H1.1), and whether immersive VR led to higher ENJOYMENT than PC (H1.2). Tests of normality (Shapiro–Wilk) and homogeneity of variance (Levene's test) indicated that the data does not meet the required assumptions for parametric testing. Therefore, a Kruskal–Wallis test was performed. The test found significant differences between the groups, H(2) = 17.40, p < .001. Post-hoc Dwass–Steel–Crichtlow–Fligner pairwise comparisons were performed and Cliff's Delta Calculator used for effect sizes. The tests revealed that VR users reported significantly higher enjoyment than PC users (W = 3.66, $p = 0.026$, $\delta = 0.359$) and text readers (W = 5.60, p < .001, $\delta = 0.549$), suggesting a medium and high effect, respectively (IIPUS, n.d.). The comparison between PC players and text readers was non-significant, W = 2.72, p = 0.132. Fig. 2 shows the ENJOYMENT values across the three participant groups.

4.2. Immersion

Next, we compared the three groups to examine whether technological immersiveness is correlated with IMMERSION (H2). Tests of normality and homogeneity of variance indicated that the data follows the required assumptions for parametric testing. Therefore, a one-way ANOVA was performed. Although the mean value was higher in the game groups (PC = 5.03, VR = 5) than in the control (4.76), the test did not find a significant difference between the three groups, F(2, 67.5) = 0.848, p = 0.433. Fig. 2 shows the IMMERSION values across the three participant groups.

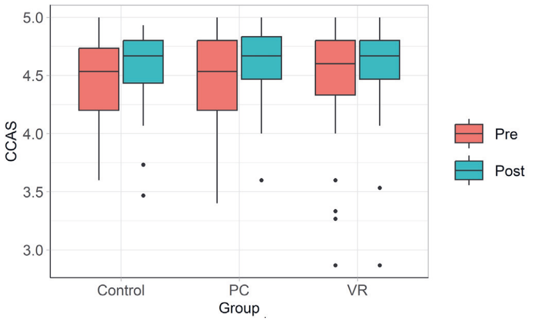

Fig. 3. Participants' CCAS before and after the treatment.

Table 3
Pre- and post-treatment comparison of participants' CCAS, CCBEL and CACT.

Group	Mdn		Z	p	r
	Pre	Post			
Climate change attitudes (CCAS)					
Control	4.53	4.67	85	p = .002	0.609
PC	4.53	4.67	87.5	p < .001	0.647
VR	4.60	4.67	69	p = .003	0.607
Climate change beliefs (CCBEL)					
Control	4.70	4.80	94.5	p = .011	0.500
PC	4.70	4.90	82	p = .015	0.495
VR	4.90	4.90	62.5	p = .011	0.547
Individual climate action beliefs (CACT)					
Control	4.20	4.40	91	p = .005	0.552
PC	4.20	4.20	61	p = .003	0.625
VR	4.00	4.20	99	p = .026	0.436

Note. Z = test value. p = significance. r = Rank biserial correlation.

4.3. Climate change attitude

4.3.1. Before–after differences

After focusing on ENJOYMENT and IMMERSION, we proceeded to examine whether the intervention had an effect on participants' climate change attitudes (H3.1), for which we compare the data before and after the intervention (see Fig. 3). Due to the data not meeting normality assumptions, we performed Wilcoxon signed-rank tests (one-tailed) for CCAS and the CCBEL and CACT constructs. The tests for each group showed a significant difference in the pre-post comparison in all three cases, as shown in Table 3. A Holm–Bonferroni correction was applied to each pair of results involving CCAS and either of its dimensions, CCBEL or CACT, for the same treatment group. All results remained significant at the 0.05 alpha level after applying the correction.

4.3.2. Comparison of attitudinal shifts between groups

Next, we examined possible differences in attitudinal effects between the game-based conditions and the control (H3.2) and between the three groups, where VR is expected to lead to a larger shift than PC and PC to a larger shift than the control (H3.3). For this, we performed an analysis of variance on the participants' attitudinal shift (that is, post–pre). Not meeting the assumptions for a parametric test, we performed a Kruskal–Wallis test, which found no significant differences in shift for CCAS ($H(2) = 0.209$, $p = 0.901$), CCBEL ($H(2) = 0.041$, $p = 0.980$) or CACT ($H(2) = 0.762$, $p = 0.683$).

To test whether IMMERSION was positively associated with shifts in climate change attitudes (H3.4), we first visually explored the data, which appears to be disperse rather than showing any discernible consistent patterns, as shown in Fig. 4.

Table 4
Spearman correlation tests involving IMMERSION and CCAS, CCBEL, and CACT.

		CCAS	CCBEL	CACT
IMMERSION	*ρ*	−0.003	0.039	−0.112
(all)	*p*-value	0.513	0.345	0.871
IMMERSION	*ρ*	−0.017	−0.074	−0.059
(control)	*p*-value	0.538	0.663	0.631
IMMERSION	*ρ*	−0.018	0.042	−0.172
(PC)	*p*-value	0.542	0.405	0.839
IMMERSION	*ρ*	−0.026	0.174	−0.123
(VR)	*p*-value	0.560	0.159	0.759

Note. Hypothesis is positive correlation.

Table 5
Pre- and post-treatment comparison of participants' ESE.

Group	Mdn		Z	p	r
	Pre	Post			
Control	6.40	7.20	150.5	p = .010	0.463
PC	6.30	7.60	81	p < .001	0.728
VR	6.70	7.50	161.5	p = .010	0.457

Note. Z = test value. p = significance. r = Rank biserial correlation.

In addition to the exploratory visualizations, a correlation matrix was created in Jamovi (see Table 4) to test H3.4. Given that visual examination indicated no clear linear relationships and normality tests revealed most of the data to be non-normally distributed, we decided against using the Pearson correlation coefficient. Instead, Spearman's rank correlation coefficient was used to assess the presence of a monotonic relationship between each pair of datasets. The results imply that IMMERSION is not significantly correlated with CCAS, CCBEL, nor CACT.

4.4. Environmental self-efficacy

4.4.1. Before–after differences

Next, we compared the participants' ESE data from before and after the intervention to see whether a change had occurred (H4.1) (see Fig. 5). Due to the data not meeting normality assumptions, we performed Wilcoxon signed-rank tests (one-tailed). The tests showed a significant difference in the pre-post comparison (see Table 5).

4.4.2. Comparison of ESE shifts between groups

Next, we examined possible differences in ESE effects between the game-based conditions and the control (H4.2). For this, we performed an analysis of variance on the pre-post change in ESE to examine possible differences between groups. Not meeting the assumptions for a parametric test, we performed a Kruskal–Wallis test, which found no significant differences in ESE shift ($H(2) = 4.06$, $p = 0.131$).

To test whether IMMERSION was positively associated with a shift in ESE (H4.3) we first visually explored IMMERSION plotted against shifts in ESE (post–pre). The data does not seem to show any discernible consistent patterns, as shown in Fig. 6.

In addition to the exploratory visualizations above, a correlation matrix was created in Jamovi (see Table 6) to test H4.3. Due to no clear linear relationships and non-normal distribution, Spearman's rank correlation coefficient was used to assess the presence of a monotonic relationship between each pair of datasets. The results imply that IMMERSION is not significantly correlated with ESE.

4.5. Exploration of relationships between interest/enjoyment and climate change attitude and environmental self-efficacy

To answer RQ1, which aims to explore the distribution of attitudes and self-efficacy in relation to interest/enjoyment, we conducted data visualization-based explorations. The visualizations involving ENJOYMENT plotted against shifts in CCAS and its factors or ESE (post–pre) did not seem to yield any discernible consistent patterns, as shown in Fig. 7.

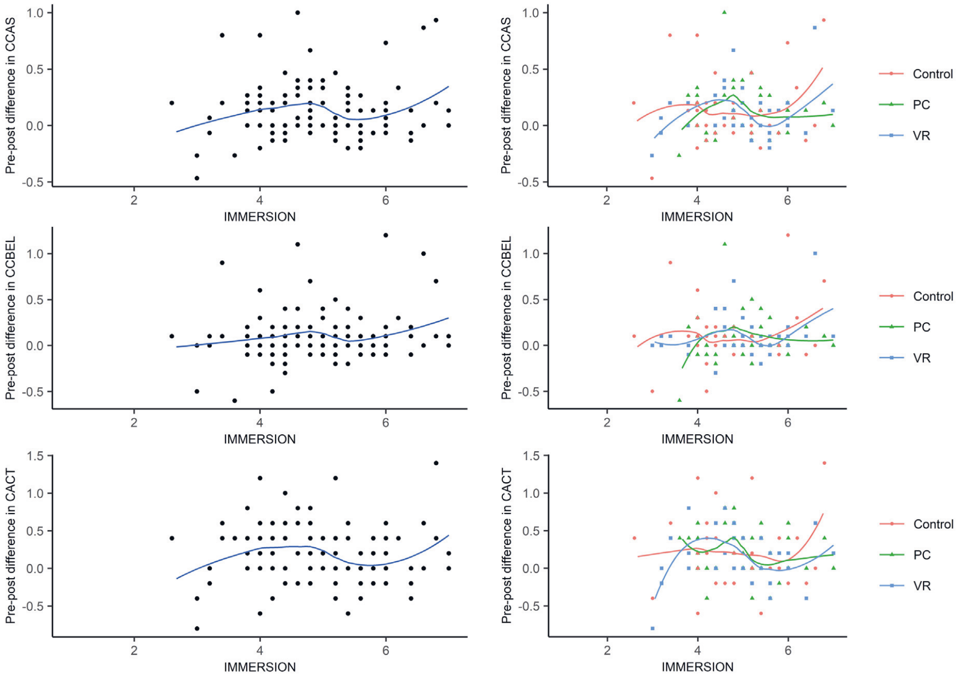

Fig. 4. Shift in CCAS, CCBEL and CACT based on IMMERSION for all participants (left) and divided by treatment group (right).

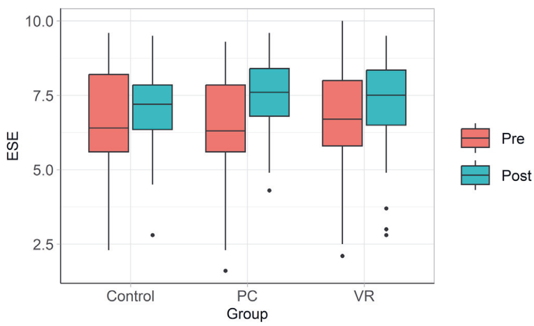

Fig. 5. Participants' ESE before and after the treatment.

Table 6
Spearman correlation tests involving IMMERSION and ESE.

		ESE
IMMERSION (all)	*ρ*	−0.093
	p-value	0.828
IMMERSION (control)	*ρ*	−0.204
	p-value	0.880
IMMERSION (PC)	*ρ*	−0.309
	p-value	0.964
IMMERSION (VR)	*ρ*	0.139
	p-value	0.212

Note. Hypothesis is positive correlation.

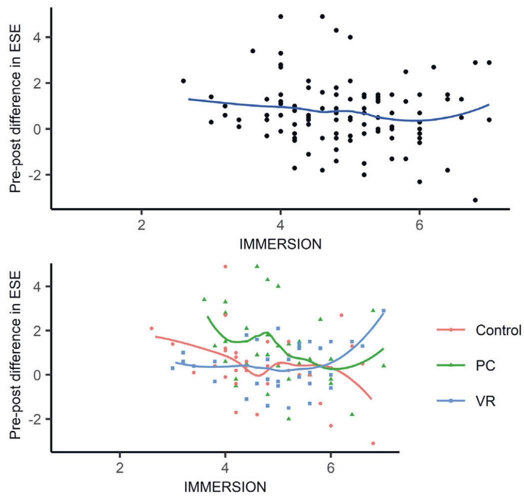

Fig. 6. Changes in ESE based on IMMERSION for all participants (top) and divided by treatment group (bottom).

4.6. *Exploration of pro-environmental intentions and behaviors*

Of 105 participants, 102 signaled their willingness to engage in climate action at the end of the game (35 in each group) or after reading the text (32). Because some of the expected values were under

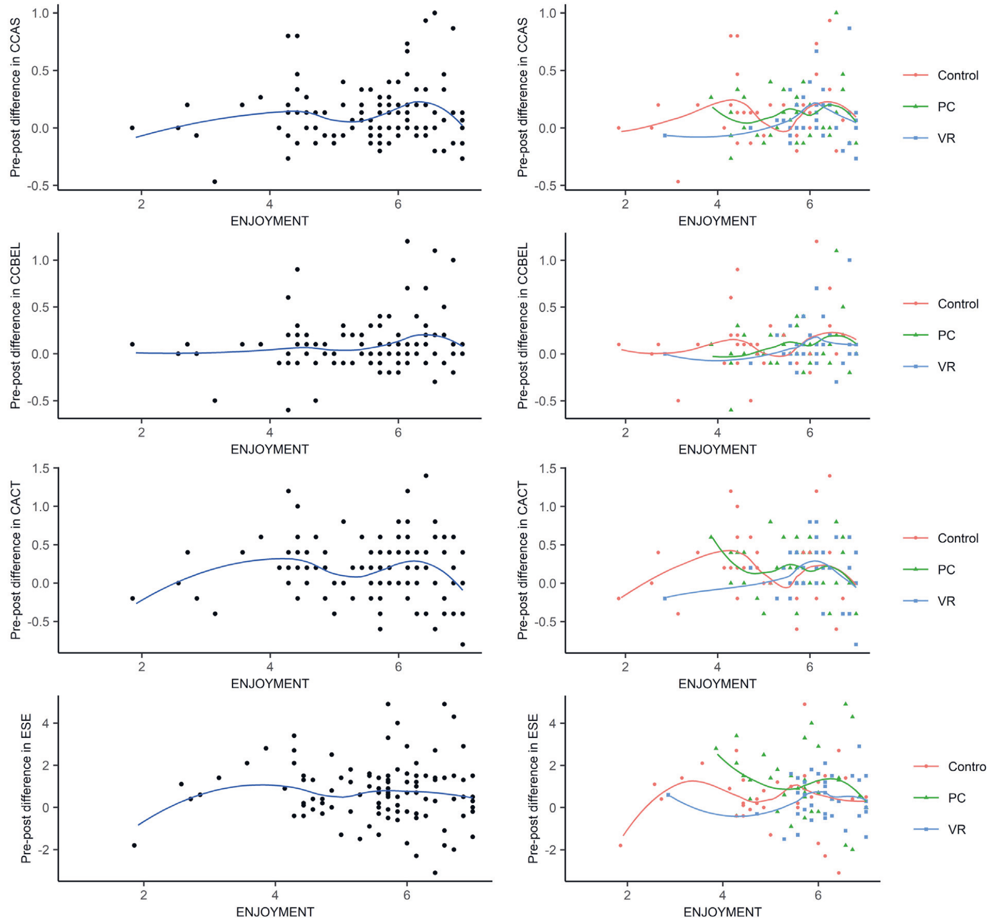

Fig. 7. Changes in CCAS, CCBEL, CACT and ESE based on self-reported ENJOYMENT for all participants (left) and divided by treatment group (right).

5, we conducted a Fisher's exact test (FET) to detect possible significant differences between the three groups. However, the result was non-significant ($p = .105$).

Of the 102 participants who chose to receive action proposals, 28 chose to receive further information to read, 25 selected individual actions, 21 chose collective action, 12 selected civic actions, 8 selected advocacy, and 8 chose to receive art-related suggestions.

Of the 102 participants, 42 answered the follow-up questionnaire sent 10 days later. Of these participants, 11 had chosen individual action, 9 information, 8 collective action, 7 civic action, 4 advocacy, and 3 art-related actions. Fifteen participants self-reported having done one climate action, 9 declared having taken steps towards it, 12 said that they would do it in the future, 3 said that they had not done their intended action, and 3 declared having forgotten their intended action.

The respondent distribution is similar when comparing by group (control: 14; PC: 13; VR: 15), as are their specific answers regarding action completion and their opinion on whether they had been inspired to take further action after participating in the experiment (see Table 7). The results of χ^2 tests of independence (or FETs, if any of the expected values was under 5) involving each of the six categories in Table 7 yielded non-significant results, indicating that there are no significant differences between the three treatment groups in any of them.

Table 7
Self-reported participant climate action completion after the experiment.

Group	Done	Steps	Future	No	Forgot	Inspired
Control	6	3	4	1	0	11
PC	3	4	3	1	2	11
VR	6	2	5	1	1	12
Total	15	9	12	3	3	34

5. Discussion

In this article, we have tested various hypotheses related to the use of a narrative climate change game in PC and VR and its comparison to a control, a text-based informational equivalent (see Table 8 for a summary of statistical testing outcomes). Our findings suggest that all three conditions increased climate change attitudes and environmental self-efficacy, but the study did not find significant differences between the three conditions. We found significant differences between the self-reported enjoyment of VR players and those in the other groups, which supports our hypothesis that playing in VR would be more enjoyable than playing on PC and partially supports our hypothesis that playing the game would be more enjoyable than reading the text. However, we

Table 8
Summary of hypotheses, including the statistical techniques used and the outcome.

Hypothesis		Statistical test	Outcome
H1.1	Playing the game in any form will be significantly more enjoyable than reading the text.	Kruskal–Wallis & Dwass–Steel–Crichtlow–Fligner	Partially supported
H1.2	Playing the game in VR will be significantly more enjoyable than playing on PC.	Kruskal–Wallis & Dwass–Steel–Crichtlow–Fligner	Supported
H2	Technological immersiveness will be positively associated with self-reported immersion.	One-way ANOVA	Not supported
H3.1	The intervention in any of its forms will positively affect participants' climate change attitude.	Wilcoxon signed-rank	Supported
H3.2	The game-based conditions will result in a larger climate change attitude shift than reading the text.	Kruskal–Wallis	Not supported
H3.3	Technological immersiveness will be positively associated with a shift in climate change attitude.	Kruskal–Wallis	Not supported
H3.4	Self-reported immersion will be positively associated with a shift in climate change attitude.	Spearman's rank correlation coefficient	Not supported
H4.1	The intervention in any of its forms will positively affect participants' environmental self-efficacy.	Wilcoxon signed-rank	Supported
H4.2	The game-based conditions will result in a larger environmental self-efficacy shift than reading the text.	Kruskal–Wallis	Not supported
H4.3	Self-reported immersion will be positively associated with a shift in environmental self-efficacy.	Spearman's rank correlation coefficient	Not supported

did not find significant differences in self-reported immersion across conditions, as well as significant correlations between immersion and changes in climate change attitudes and environmental self-efficacy. We also explored those variables in relation to enjoyment, finding no clear data patterns. Finally, our exploration of participant behavior yielded similar results for all three conditions, both in commitment to action and self-reported completion ten days after the intervention.

The findings regarding enjoyment were partially surprising, as it was expected that PC players would have found playing a game significantly more attractive than reading a text. However, there is precedent about games not being more motivational than traditional instruction in educational settings (Wouters, Van Nimwegen, Van Oostendorp, & Van Der Spek, 2013). In this intervention, the use of a text in a narrative style, with rich descriptions and direct references to the reader, and supported by flowcharts, may have contributed to a heightened interest if compared to a hypothetical text missing those features. At the same time, the nature of the experiment required the game conditions to be rather text-heavy, which may have reduced the distance between the different experiences. While immersive VR may be attractive due to its novelty and capacity for stimulation, interacting with a computer can be seen as a more mundane activity. Furthermore, the fact that the experiment was advertised as concerning climate change and the participants enrolled voluntarily may have attracted a sample that was particularly willing to engage with environmental content irrespective of the format. In addition, the experiment's setting, a university lab, may have also attracted a sample who is used to reading and is generally interested in text-based science dissemination.

The fact that no significant differences in self-reported immersion were found between conditions was also surprising. While the measurement instrument used, the "Immersion" subscale of GAMEFULQUEST, refers to immersion as a construct that signals involvement with the game rather than spatial presence, or the feeling of being transported to a different space (Cairns et al., 2014), it was nonetheless hypothesized that participants would report higher levels of immersion in the game conditions, and in VR in particular due to its higher potential for cognitive absorption (Kampling, 2018). Once again, the fact that the text was generally perceived as interesting and the game was largely text-based may have affected the audience's engrossment to an extent that no significant difference could be found, especially given the existence of narrative transportation as an immersive phenomenon (Green, 2021).

Participant attitudes were in general high before the stimulus, with a median value of 4.6 out of 5, which adds to the perception that this was a rather environmentally aware (and predisposed) sample. While the margin for increment was quite limited, the intervention increased the attitudes with a generally medium effect size. The fact that the action-related attitudinal component had a median significantly lower than the climate change beliefs component (4.2 vs. 4.8) implies that the general trust in one's own role as mitigating agents somewhat lagged behind interest and concern.

The findings on the intervention's attitudinal effects require further discussion, since three of the four proposed hypotheses were rejected. While we expected that all the conditions would have an impact on the participants' attitudes, the lack of difference between their effects may be explained by the similarities in the techniques employed. As both the text and the game largely relied on written communication to transmit information, the added value of playing the game (i.e., via features such as goal- and exploration-based interactive discovery of the story, a guiding character, graphical elements giving substance to the descriptions, and the possibility to choose dialog options) was not enough to drive significantly different attitudinal outcomes. As the use of a simulation in a similar experimental design also provided a similar result (Soekarjo et al., 2015), our study adds to the existing evidence with a narrative linear game and the involvement of an immersive VR condition. Regarding the role of VR, a comparison study showed VR visualizations raising environmental awareness as much as other methods, but not significantly more (Thoma et al., 2023). Where differences have existed, these tend to be attributed to a higher presence experienced in immersive VR, which was not observed in our study (Thoma et al., 2023). While we did not find a clear correlation between immersion and climate change attitudes, our results do not directly contradict others' assumption that presence can amplify media effects, especially given the different ways in which immersion and presence can be measured. Since it has been suggested that visual realism may not be a relevant aspect in shifting attitudes (Thoma et al., 2023), which supports the potential of cartoon-like environments like the ones used here, the effort to create experiences that foster presence in a clearer way may focus on creating more vivid stimuli (Bailey et al., 2015), that is, higher protagonism of the 3D multimedia environment and interaction with it over text-based communication.

The fact that there were no differences between the groups in terms of self-reported immersion also renders the lack of correlation with attitude somewhat unsurprising. The lack of an apparent relationship between enjoyment and attitudes/self-efficacy may also be explained partially through the fact that participants came to the experiment voluntarily, so even without experiencing a large degree of enjoyment, they may have generally paid attention to the text or game and attempted to do as best as they could.

In terms of self-efficacy, the similarity of the results may be explained as well by some of the arguments put forward when discussing attitude. While not comparatively as high, the participants' median self-efficacy before the intervention was rather considerable (6.6/10), although by the end it was raised to a median of 7.4. It is apparent as well that the additions provided by the game, both interactive and in terms of visualization, were not enough to drive different self-efficacy outcomes. This can be explained by the fact that the game did not feature situations where behavioral learning was practiced, but it rather supported self-efficacy through textual elements. Instead of simulating environmental challenges and providing opportunities for problem-solving and skill-building, most of the game used challenging situations to depict climate change issues, leaving the bulk of the solutions-oriented part for the end. Finally, when examining the three conditions individually, it can be seen that PC had a noticeably, although non-significant, larger effect than text and VR on environmental self-efficacy. Some possible explanations for its advantage over immersive VR include its potential ease of use and familiarity, as well as the fact that players in immersive VR may be more inclined to explore their surroundings while experiencing more difficulty and tiredness when reading (Knaack, Lache, Preikszas, Reinhold, & Teistler, 2019).

Our final area of focus in this article, the participants' PEI and PEB, yielded no differences in patterns when comparing the three conditions. This is consistent with the lack of difference in attitudes and self-efficacy. Even so, 34% of the experiment participants answered the final survey declaring that they had either done a climate action, progressed towards it, or planned to do it in the future. While it is possible that some of these actions would have been done even without the intervention, the result provides a point of comparison for similar future research.

5.1. Limitations and future research avenues

This study had some limitations that should be acknowledged, pointing at the same time towards future research avenues. First, and as said above, the design involved an experiment where willing participants were recruited. Although they received a small compensation for their participation, it can be assumed that a large proportion of them were particularly interested in the topic and were used to consuming information about it. Since our sample comprises participants that were generally concerned about climate change, young, and formally educated, our study should be complemented with other samples and in other contexts to arrive at a truly representative picture. Future research should also take into account that, despite the lack of clear comparative advantage in terms of attitudinal and self-efficacy improvement, games may be more attractive to audiences who may not be willing to read a text, as well as offer potential memorability (Pfirman et al., 2021) and recommendation advantages. Qualitative techniques such as interviews or focus groups may offer deeper insights into the participants' thoughts and opinions (Fernández Galeote et al., 2022).

The sample size is another limitation, since it may have been insufficient to detect small effects. The statistical examination of PEI and especially PEB will benefit from larger sample sizes in future studies, since in these cases the data were smaller than the overall sample. Therefore, the statistical test results referring to PEI and PEB reported here should be interpreted critically and need examination with larger samples.

Regarding the behavioral outcomes, two limitations should be taken into account. First, all of the groups included a prompt to signal the intention to participate in climate action. Therefore, we cannot isolate the effects of this commitment. This prompt was shown at the end of the game and immediately after reading the text, which could have influenced somehow the participants' responses to the subsequent survey by introducing a bias where the commitment impels participants to be consistent in their subsequent behavior, including reporting their attitudes (Lokhorst, Werner, Staats, van Dijk, & Gale, 2013). Second, we did not compare our participants to others who had not been exposed to a comparable stimulus that would offer a true baseline for pro-environmental behavior. Thus, this intervention should be complemented with others that test attitude change and propensity to act without offering an explicit commitment, nor a comparable treatment.

The measurement methods used also have limitations. First, in terms of what may lie beyond our capacity to observe and report: as long as attitude and self-efficacy depend partially on pre-existing personal variables, such as emotions, ideology, and physical and social constraints (Kollmuss & Agyeman, 2002), self-reported measures will remain difficult to assess and predict, including their possible translation into hope or productive engagement, as even the most engaged person needs times of disconnection (Pihkala, 2022). Second, we measured behavior through voluntary self-report ten days after the intervention. We can only assume that those who did not answer the survey did not do anything, and that those who answered were fair in their reporting. Other methods of assessing behavior may complement our findings.

A further limitation involves the statistical analyses performed. Due to there being different constructs of interest, multiple statistical tests have been done, which can raise the likelihood of detecting spurious relationships. However, the results found are generally clear in terms of significance, and corrections have been applied to those cases in which multiple tests referred to the same population and hypothesis and significant results were found.

Finally, we would like to echo previous works (Fernández Galeote et al., 2021; Soekarjo et al., 2015) in continuing to encourage rigorous designs where games and immersive media are compared to informationally similar conditions. Rather than assessing if games and/or immersive VR can impact climate change engagement positively, which seems to be a rather consistent finding, it is time to understand more deeply and in context how they do so, and what their comparative advantages may be.

CRediT authorship contribution statement

Daniel Fernández Galeote: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing. **Nikoletta-Zampeta Legaki:** Conceptualization, Methodology, Formal analysis, Funding acquisition, Investigation, Visualization, Supervision, Writing – review & editing. **Juho Hamari:** Conceptualization, Methodology, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.chb.2023.107930.

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