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Effects of Designing a Narrative-Based Video Game on High School Students' Climate Change Perspectives

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Abstract
This study examined how high school students' participation in designing an extended reality (XR) video game influenced their understanding of climate change. The *Make Games, Save the World* program, supported by a National Science Foundation grant, engaged students, from backgrounds underrepresented in STEM fields, in a year-long, out-of-school initiative. Working collaboratively in narrative and design teams, students created a story-driven game set in a fictional future world impacted by extreme heat and water scarcity. To assess changes in understanding, participants completed Personal Meaning Maps (PMMs) before and after the program. PMMs were analyzed for extent (quantity of relevant vocabulary), breadth (diversity of concepts), and depth (sophistication of understanding). Findings indicated that students doubled the extent of their vocabulary, with consistent gains across initial knowledge levels. The breadth of concepts also expanded, reflecting a deeper engagement with the multifaceted causes and impacts of climate change. Additionally, some students advanced to higher levels of sophistication, integrating complex ideas such as societal impacts and interrelated systems. These results suggest that designing XR games in a collaborative, interdisciplinary setting can promote critical thinking and enhance understanding of complex topics like climate change.

Keywords Game design · Extended reality (XR) · STEM engagement · Project-based learning · Climate change · Informal learning

Extended reality (XR) video games, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), have emerged as powerful tools for creating immersive and interactive experiences. Research indicates that XR games have the potential to significantly impact users by focusing attention and enhancing engagement, fostering emotional connections, and sometimes even promoting behavioral change (Bennett et al., 2021; Taborda et al., 2025). For instance, studies have demonstrated that XR environments can elicit empathy by placing users in scenarios where they experience unfamiliar environments or become aware of perspectives that might differ from their own (Lee et al., 2024; Young et al., 2021). Less understood is how the process of designing such games might impact the game creators themselves. While a fair amount of attention has been given to the effects on users, the educational benefits experienced by game developers remain an underexplored area of research. This study addressed this gap by examining how high school students' participation in the design of an XR game influenced their understanding of climate change, as measured through Personal Meaning Maps (PMMs).

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Background

Supported by a National Science Foundation grant, the *Make Games, Save the Planet* pilot program was developed as an out-of-school time initiative for high school students. The project, situated in the desert Southwest of the USA, recruited 12 high school students primarily from racial and ethnic groups that are underrepresented in STEM fields. These students, who attended various high schools, met once a week throughout the academic year at a local university facility to explore topics related to climate change, game development, and storytelling. Working collaboratively, they chose to focus on drought and water-related issues and then designed a story-driven game. Once the students had decided their game would be about drought, local experts were invited to provide presentations on relevant topics, such as water management, conservation, and rights, and to review and provide feedback on the prototype game. Mini-lessons and student-centered activities that focused on these topics were also integrated into the weekly sessions.

Even though the game that the students would design is set in a somewhat dystopian and fictional future world, this theme of drought and water management was chosen by them to reflect a critical local issue, highlighting how climate change exacerbates challenges such as diminishing water supplies, increasing demand, and the effects of prolonged droughts on ecosystems and communities. The overarching educational goal for their XR game was to engage players in understanding the impact of climate change and consider potential solutions.

The 12 students met weekly. Some of the weekly sessions were dedicated to whole group interactions led by one or two project facilitators and/or specialists. The facilitators and specialists discussed topics such as engaging audiences through storytelling, overcoming technical challenges in game design, and using evidence-informed strategies to engage communities in learning about climate change. Following the initial sessions, approximately half or more of the time was dedicated to students working collaboratively within a project team structure. This structure mirrored real-world STEM workplaces, where teams focus on different aspects of a joint project with the shared goal of designing and delivering a cohesive final product (Schöttle & Tillmann, 2018).

As the project progressed, the students opted to be members of one of two development teams based on their interests and skills. The Narrative Team developed the storyline, including the characters, game mechanics, and challenges the game characters would encounter. The Design Team was responsible for building the digital environment of the game using the Unreal game engine, including the game's look and feel, physical spaces, and movement of the game characters through the world. A game engine, such as Unreal, is a software platform that developers use to create interactive digital environments, combining graphics, sound, and user interactions into a playable experience. Together, both groups built a fictional world that immerses players in the demanding environment of a future community of the Southwestern United States where temperatures continue to rise and water becomes ever more precious.

The collaborative nature of the project required the Narrative Team and Design Team to work closely together, often influencing one another's work. For instance, the Design Team focused on creating the visual and interactive elements of the game, including environments and user interface features, while the Narrative Team concentrated on crafting the storyline, developing characters, and ensuring that the narrative elements were compelling. At times, the storyline developed by the Narrative Team required the Design Team to create new digital elements to accommodate specific plot points or character challenges. Conversely, technical constraints or creative innovations by the Design Team occasionally prompted the Narrative Team to adapt or expand the storyline to align with the evolving digital environment. This interplay between narrative and design mirrored professional game development processes, where creativity and technical execution are deeply intertwined (Djafarova et al., 2023).

The *Make Games, Save the Planet* pilot program adhered to a theory of change underpinned by three primary beliefs: that (1) by creating a game about local impacts of climate change, young people will increase their understanding of climate science and sustainability practice; (2) by collaborating in a youth-led, adult-guided game design process, young people will strengthen their leadership confidence and skills; and (3) by engaging community members in their games, young people will increase their interest in STEM careers as a way to create the future they want to live in. This study focused on the first belief, exploring how participation in the game design process influenced young people's understanding of climate change. Specifically, this study examined whether designing a narrative-driven XR game helped students deepen their knowledge of climate change concepts and develop more nuanced perspectives on interrelations and its impacts.

By grounding the game design process in a youth-driven, project-based framework, it was believed that the program would provide students with opportunities to think critically within the context of climate change. As the game structure developed and students engaged in discussions about the game and related climate change concepts, it was also hoped that the process would encourage them to consider scientific causes, societal impacts, and potential solutions. This study examines the extent to which this approach supported students in expanding their knowledge and making meaningful connections among the many factors that cause and contribute to climate change. To understand the learning that occurred through this climate-focused game design program, we framed our study around the following research question:

Research Question

How did students' understanding of climate change evolve over the course of the program, particularly in terms of vocabulary, breadth of ideas, and depth of explanation?

Relevant Literature

Inclusion of Underrepresented Youth

Given the critical need to attract more young people to STEM fields and the benefits of diverse participation in STEM, it has often been considered important to provide opportunities for young people from groups that are underrepresented in the STEM fields to develop their interest in STEM careers and understanding of pathways to pursue them (Committee on STEM Education, 2018; Honey et al., 2020). To address this need, the approach of the project studied was that of an informal, out-of-school-time program designed to strengthen the STEM interests of high-school-aged students and help them explore possible STEM careers.

Research shows that informal learning programs can improve participants' interest and motivation to learn STEM, strengthen their identity as STEM learners, complement and support learning in school, and encourage pursuit of STEM occupations (National Research Council, 2015). Situating the learning in social contexts that allow learners to relate STEM to life experiences and draw on supportive networks can help them persist in STEM (Bevan et al., 2018). These characteristics of STEM learning environments are particularly important for underrepresented learners, who may face sociocultural dispositions that do not traditionally include STEM or can be discouraged by the lack of STEM role models (Arbona & Nora, 2007; Osborne et al., 2003; Vincent-Ruz & Schunn, 2018).

The game design project we studied drew on research demonstrating the efficacy of bringing students together to collaboratively work toward positive social change (Birmingham et al., 2017; Gupta, et al., 2011). Collaborative efforts in STEM contexts provide opportunities for students to engage with real-world challenges while developing skills in teamwork and critical thinking (Mebert, et al., 2020). This relates to culturally sustaining, culturally relevant, and other asset-based pedagogies, which view the practices of communities of color as strengths and resources and allow educators and researchers to better support and study STEM learning (Gay, 2018; González et al., 2005; Ladson-Billings, 1995; Paris & Alim, 2014). Such frameworks shift the focus from perceived deficits in students' knowledge to recognizing and building on the expertise and perspectives they bring to learning environments (Brown-Jeffy & Cooper, 2011).

Luehmann et al. (2023) identified four core practices for culturally sustaining STEM pedagogy: having a purpose that is meaningful to youth and centers justice; eliciting local stories and interpretive power; bringing in diverse expertise; and using STEM to make a difference and advocate for justice. Elements of this program reflected these practices, such as focusing on water scarcity and climate change, topics that were relevant to the students' regional context. The program included opportunities for students to contribute their perspectives to the game's narrative and draw on input from experts in sustainability and game design. These features aligned with efforts to connect STEM learning to real-world issues, while also engaging students in broader discussions about environmental challenges.

Climate Change and Game Design

Climate change is a globally pressing issue with urgent and far-reaching implications for local communities around the world. In the USA, polls indicate that the two overlapping focal audiences of the *Make Games, Save the Planet* project—young people and Hispanic/Latinx groups—recognize the complex social and environmental problems created by climate change; are more committed than other groups to take action; and view climate solutions as requiring both individual and collective efforts (Ballew et al., 2019; Krogstad, 2015; Leiserowitz, et al., 2017, Leiserowitz, et al., 2024; Tyson et al., 2021; Washington Post-Kaiser Family Foundation, 2019). This is important, because research shows that teens—particularly girls and members of minority ethnic and racial groups—are motivated to enter STEM to solve issues they care about (Estrada et al., 2016; Miller et al., 2000; Triandis, 1993).

Research also indicates that by designing games, young people can interact with STEM knowledge and practices and develop a wide range of skills and ways of thinking (Akcaoglu & Koehler, 2014; Khaled & Vasalou, 2014; Parekh et al., 2021). The interplay between the systems of a well-designed educational game can allow both game makers and players opportunities to explore STEM concepts and practices, including the systems involved in climate, environmental, and sustainability science (Klopfer et al., 2009; Parekh et al., 2021; Waddington & Fennewald, 2018). Game mechanics can also demonstrate connections among individual actions, larger social structures, and the natural environment; encourage collaboration and collective solutions; and promote conversation about normative science ideas (Akcaoglu & Green, 2019; Flood et al., 2018; Rafael et al., 2010; Rooney-Varga et al., 2018).

While the sociocultural dimensions of learning through game design are less studied, a growing body of research shows that it can be engaging and culturally relevant for groups that are underserved by STEM education and underrepresented in STEM fields (Benson et al., 2017; Newton et al., 2020). Games blend reality and fiction to create a plausible world that players can influence and shape (Abraham, 2018), acting as themselves or taking on a role (Wu & Lee, 2015). These characteristics allow game designers to envision STEM-informed alternative futures and actors that connect to their values, interests, and sense of self (Clark et al., 2009; Germaine & Wake, 2024) and to experiment with and reflect on different identities (Barab, et al., 2010; Galeote et al., 2022). Co-designing games with peers can also contribute to promoting designers' social skills, confidence with technology and storytelling, and ability to articulate game rationale and principles—skills that draw directly on the humanities and enrich STEM learning (Kafai & Burke, 2015).

Prior research also demonstrates that interacting with STEM experts and role models during the game design process can broaden young people's awareness of potential STEM careers, helping them identify areas that interest them and making them feel more confident in a STEM pathway (Clark & Sheridan, 2010; Rheingold & Seaman, 2017). Additionally, working with likeminded peers and role models during the design process can help players see themselves in STEM (Callahan, et al., 2019; Denner et al., 2009; Kafai & Burke, 2015).

Methods

Student Participants

The *Make Games, Save the Planet* leadership team worked with several community and neighborhood organizations to recruit young people to participate in the program, as well as high school teachers from local districts, including Title I schools. The goal was to select a dozen participants who had a range of interests and skills in areas such as STEM (with an emphasis on climate and environmental sciences), storytelling and art, and game design and digital technologies. While the program was open to all students—and not limited to those from racial and ethnic groups that are underrepresented in STEM—the project leaders made a particular effort to recruit broadly in order to attract students of diverse identities and backgrounds, including Hispanic/Latinx groups.

The leadership team received over 120 applications and selected 25 high school students for a preliminary meeting with project leaders. To make the first selection, members of the project leadership independently reviewed all applications, noting those that they felt were strong based on the thoughtfulness and thoroughness of their replies to the application questions. The project leaders then convened to discuss and finalize their potential selections, at which point they also considered the balance of the group in terms of expressed interest in game design and/or climate change.

During the preliminary meeting with the 25 potential participants, they asked questions and engaged in activities designed to observe their interactions and skills. They also toured the university facility, which was equipped to support the development of media experiences, including virtual worlds and video games. In small groups, students completed a storytelling activity and presented their ideas, followed by a whole-group discussion where they shared their interest in the project and suggestions for making the program engaging. Discussion questions were provided in advance to help participants feel confident sharing their ideas. Throughout the process, the leadership team observed how participants collaborated and contributed to group interactions.

Ultimately, 12 individuals with diverse backgrounds, interests, and skills were selected. The participants reflected a range of racial, ethnic, and gender identities, as well as varied socioeconomic backgrounds. All 12 of the high school students, with parent or guardian consent, agreed to participate in our research study.

Project Overview

During the first semester of the program, project facilitators focused on developing relationships among the young people and strengthening the group's understanding and skills related to climate change, sustainability, game design, storytelling, and teamwork. Activities included playing board games, watching short films, and reading children's books about climate and environmental science, allowing students to learn and review key STEM concepts while also analyzing and critiquing the messages and design of these educational materials (see Figs. 1 and 2). During this initial stage, all students engaged in brainstorming potential game storylines and learned foundational skills in using the Unreal game engine. Overall, the activities of the first semester were intended to help the young people get to know each other

Fig. 1 Students engaged in a board game

Fig. 2 Students exploring children's books about climate issues

and allow them to explore their interests related to game development.

In the second semester, students were given the opportunity to take on a more specific role in the game development process. They indicated their preference for joining either the Narrative Team, which focused on the game's story, character, and mechanics, or the Design Team, which focused on creating the visual world of the game. In addition, students indicated if they were interested in taking a leadership role for their chosen team, which would involve helping to coordinate the group's work. About half the students indicated that they would like to join one group or the other, with the other half of the students expressing willingness to be part of either group. Additionally, two students who had already demonstrated strong leadership skills were willing to serve as the group leaders. As a result, it was relatively easy for the project leadership to create balanced and functional work groups that aligned with the students' wishes.

The Narrative team was led by a teen Director and mentored by an adult expert in sustainability and climate change, while the Design Team was led by a teen Game Development Lead and mentored by an adult expert in game design. With support from their adult mentors, the teen leaders guided their teams through the narrative and design processes, monitored milestones, identified needed resources and assistance, and facilitated the daily activities of their workgroups. University undergraduate and graduate students also worked with the young people to serve as near-peer role models and support them. Finally, additional adult experts were invited to meet with the team on occasion, for example, to help the group better understand drought, urban planning, and narrative structure. The two workgroups frequently checked in with each other, collaborating on joint tasks such as defining the game's learning objectives. Over the course of the second semester, the young leaders and team members developed greater confidence and became increasingly self-directed, while also taking care to ensure that all team members were included in decisions and had interesting work to do.

The students' prototype game, entitled *2175*, is set in a fictional future world called "Aridium," which mirrors some characteristics of the current socio-political and environmental landscape. Aridium suffers from extreme heat and drought, with most residents relying on a chip embedded in their arms to receive a daily water allotment from a powerful water utility. Players explore three distinct areas of Aridium: the "Dome," the government and financial center; the "Urban Nexus," a residential and business hub; and the "Borderlands," a rugged, outlying region. These areas reflect issues and dynamics seen in parts of the Southwestern United States, particularly those related to longstanding water rights. The central character of the game—a migrant and new water utility worker—faces challenges, navigates conflicts, and makes decisions that reveal Aridium's social, economic, and environmental complexity and affect its future. As one project participant stated, the game was "immersive, encouraged collaboration, and sparked conversations about issues we cared about."

Data Collection and Analysis

To understand how students' thinking about climate change evolved over the course of the program, we used Personal Meaning Maps (PMMs) as our primary data source. PMMs are open-ended concept-mapping tools in which participants respond to a stimulus phrase by writing down as many related words or short phrases as come to mind. For example, a student presented with the phrase "plant growth" might list terms like *photosynthesis, sunlight, fertilizer, roots,* and *water cycle.* PMMs are typically used in pre/post designs to reveal individuals' prior knowledge and track changes in understanding over time.

This method has been widely used in museum and informal learning settings because it allows for learner-driven responses and captures both the quantity and nature of conceptual change (Falk et al., 1998; Judson, 2012). PMMs are particularly well suited to contexts where individuals may hold diverse forms of knowledge and use language in varied ways. They also offer a non-threatening way to examine conceptual development in younger or less academically confident populations. Rennie et al. (2003) identified PMMs as an effective tool that can provide a multifaceted view of learning without the constraints associated with traditional evaluation tools, such as the need for control groups, which may often be impractical in many education settings. Since then, several other studies have applied PMMs to determine the effects of specific educational interventions and experiences. For example, Kamudu et al. (2022) evaluated pre and post PMMs developed by adolescents to determine how visiting a nature reserve affected views about biodiversity.

In this study, students created PMMs that depicted what they know about climate change. Specifically, at the onset of the project, students were provided a nearly blank piece of paper with only the phrase "climate over time" appearing in the middle of the paper. Black ink pens were provided to students, and they were asked to branch off the phrase and add information and concepts related to the phrase. Students completed their PMMs individually and were not permitted to interact with one another during the activity. The instructions were straightforward, and no students asked for clarification or required assistance in completing their PMM.

Administration of the post-assessment occurred 7 months later. For the post-assessment, students were given their original PMMs and asked to expand on them using a blue ink pen. This approach aligns with established Personal Meaning Map methodology (Falk et al., 1998; Kamudu et al., 2022) and reflects principles of constructivist learning, in which learners revisit and build upon prior knowledge as part of a meaning-making process. Rather than testing recall, our goal was to explore how students' conceptual understanding of climate change evolved over time. By engaging with their earlier ideas, students were able to elaborate on and deepen their initial thinking. This structure supports students in generating additional ideas by prompting connections to their earlier thinking—which aligns with our interest in tracking conceptual growth. An example of a PMM created by a student is provided in Fig. 3. The ideas represented in black ink were the student's initial ideas (pre-PMM) and near the end of the academic year, the student added to this with a blue pen (post-PMM).

The students' maps were categorized into three dimensions: *extent*, *breadth*, and *depth*, as described by Falk and Storksdieck (2005). The extent of a PMM is determined by the quantity of relevant vocabulary words and phrases present. Breadth refers to the number of concepts expressed in the PMMs, ranging from simple ones like "temperature

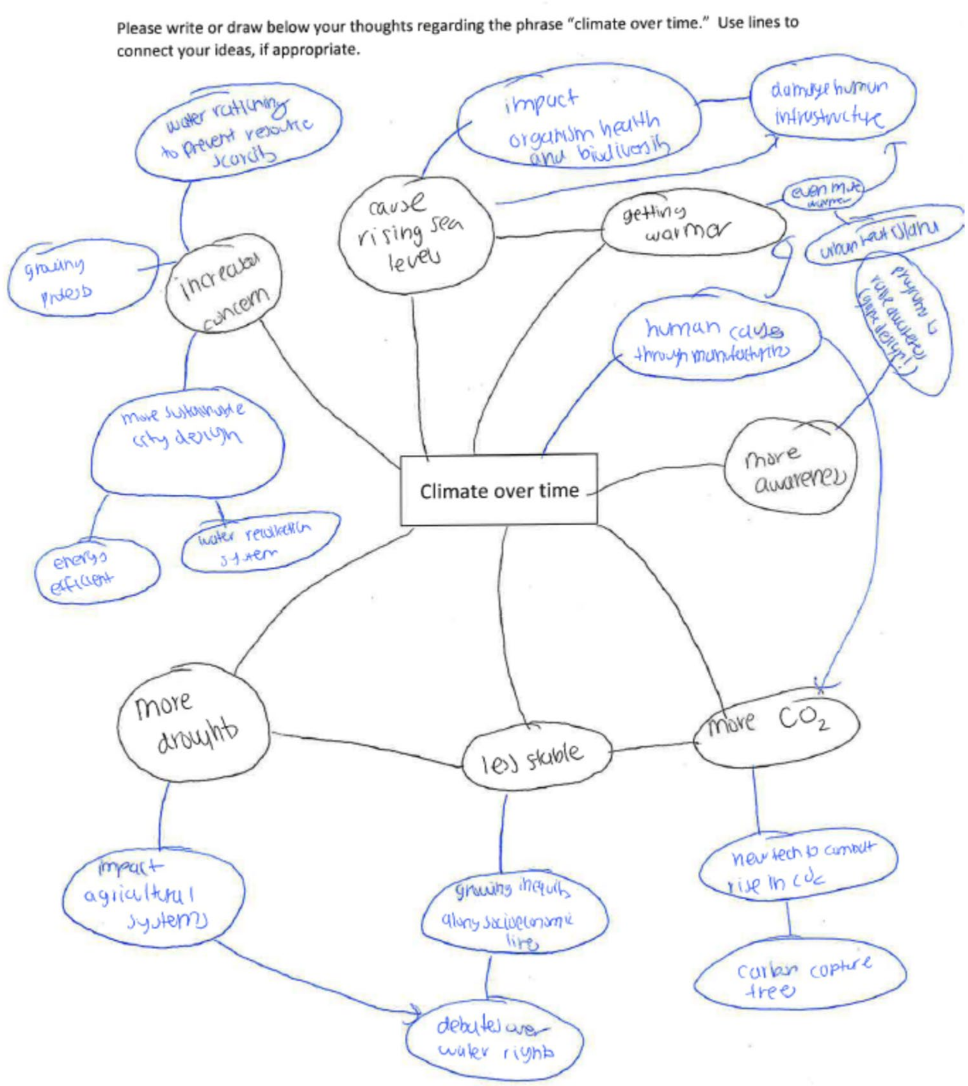

Fig. 3 Example PMM from student

Table 1 Rubric used to assess PMMs responses to "climate over time" prompt

Novice understanding (1)	Transitional understanding (2)	Informed understanding (3)
The PMM represents identification of none or few fundamental and relevant ideas. The PMM may display recognition between climate, humans and environment but without clear representation of understanding. The PMM may represent naive and/or incomplete thoughts. The PMM reflects no or little understanding of first, second, and third order effects of climate change or its causes. A focus on other environmental challenges that are not necessarily representative of the theme of *climate over time* may be present and even dominate the PMM	The PMM represents identification of some fundamental and relevant ideas. The PMM in this category often displays recognition between climate, humans and environment with some representation of moderate understanding. The PMM may demonstrate to a limited extent first order causes as well as secondary contributors to climate over time. Understanding of the complexity of climate systems may be present but not necessarily well developed. The PMM reflects little or modest understanding of first, second, and third order effects of climate change	The PMM represents identification of several fundamental and relevant ideas. The PMM displays clear recognition and understanding between climate, humans and environment, as well as associated understanding. The PMM demonstrates first order causes as well as secondary contributors to climate over time. Informed understanding is often distinguished from transitional understanding when the PMM indicates developed understanding of the complexity of climate systems. The PMM well reflects understanding of first, second, and third order effects of climate change

rising" to more intricate ideas such as "climate change is leading to increased focus on alternative energy." To assess depth, a rubric (see Table 1) is devised to classify the PMMs into different levels of sophistication: *novice understanding*, *transitional understanding*, or *informed understanding*.

To ensure consistency and accuracy of scoring, the PMMs underwent examination by two experts. The researchers examined the PMMs together and discussed identification of extent, breadth, and depth. This process occurred twice: once to examine the pre-PMMs and once to examine the changes on the post-PMMs. The researchers discussed each PMM and arrived at a consensus of scoring for all PMMs. This procedure aimed to maintain precision and reliability in the assessment of the PMMs.

Results

All 12 of the high school students in the project completed both pre- and post-PMMs. The following sections outline the degree and the ways in which their understandings of "climate over time" changed as depicted in their PMMs. Findings are presented according to the levels of extent, breadth, and depth.

Extent

On their pre-PMMs, students provided an average of 14.7 relevant words or brief phrases, with individual totals ranging from 4 to 38. On their post-PMMs, students added an average of 14.7 new relevant words and phrases, with a range of 7 to 30. Essentially, students doubled their display of vocabulary relative to the topic of "climate over time." The addition of new vocabulary was consistent across the group. The 6 students who provided the fewest relevant words and phrases on their pre-PMMs (7 to 14 words/phrases) added an average of 14.3 new words and phrases to their post-PMMs. The other 6 students, who initially provided 15 to 38 words/phrases, added an average of 15.0 new words and phrases to their post-PMMs. All 12 students added new vocabulary, indicating growth in climate-related terminology, regardless of their starting point. Notably, there was no significant correlation between the number of relevant words/phrases on their pre-PMMs and the number added on their post-PMMs, suggesting that initial knowledge level did not predict subsequent vocabulary gains.

Breadth

When analyzing for breadth, we identified and coded the relevant concepts students included in their PMMs. If a student elaborated on a concept in the post-PMM that had already appeared in their pre-PMM, it was not counted as a new concept. For example, if a student wrote “flooding” on their pre-PMM and later added “severe flooding from storms” on their post-PMM, this was treated as one related concept and coded only for their pre-PMM in the category of “natural disasters and extreme events.”

The 12 students provided a total of 47 relevant concepts on their pre-PMMs. On their post-PMMs, the students added 36 relevant concepts they had not individually indicated on their pre-PMMs. When coding the PMMs, the researchers recognized concise expressions as concepts if they indeed represented models and/or knowledgeable ideas related to climate change. Examining Fig. 3, as an example, this allowed for the student’s expression of “impacts agricultural systems” to be coded into the category of “ecosystems impacted.” Similarly, the student’s statement of “humans cause through manufacturing” was coded into the “caused by humans” category.

Table 2 presents both the number and percentage of students who provided the most prevalent concepts on their pre-PMMs and their final PMMs (i.e., pre- and post-concepts summed).

Depth

Students made overall significant gains regarding their depth of understanding the causes and effects of climate change. Two of 12 students’ pre-PMMs were evaluated to be at the highest level (level 3, informed understanding). Therefore, the remaining ten students had room to grow based on the rubric applied (see Table 1).

Among these ten students, five demonstrated an improved sophistication in their understanding based on the rubric. Three of the students advanced from novice understanding (level 1) to transitional understanding (level 2), and two others moved from transitional understanding (level 2) to informed understanding (level 3). When examining these changes by team role, the five students who showed gains included three members of the Design Team and two members of the Narrative Team. Specifically, two Design Team members and one Narrative Team member advanced from level 1 to level 2, while one Design Team member and one Narrative Team member moved from level 2 to level 3. Given the small sample size, no conclusions can be drawn about differences between roles. However, future research may explore how different roles in collaborative game design support distinct dimensions of conceptual learning.

Figure 3 depicts a student whose PMM shifted from transitional understanding to informed understanding. In this case, on their post-PMM (depicted in blue ink), the student enhanced their concept map by additionally signifying concepts related to inequality, societal disagreement, and how humans are both a cause of, and impacted by, climate change.

Discussion

This study explored how high school students’ participation in designing an interactive XR game influenced their understanding of climate change. Addressing the underexplored impact of game design on creators, the findings demonstrate that engaging in this type of process as part of a structured program may promote growth in knowledge and conceptualization of complex topics like climate change. Analysis of the PMMs indicated students doubled the quantity of relevant vocabulary they displayed, regardless of their starting point. This suggests that the program was effective in providing opportunities for all participants to engage with and internalize climate change-related terminology. The increase in the diversity of concepts articulated by students likely reflects the program’s interdisciplinary and project-based approach. By working collaboratively on narrative and design elements with adult experts and peers, students were exposed to diverse perspectives and prompted to consider various aspects of climate change, from human-caused factors to societal and ecological impacts. This finding aligns with the program’s goal of fostering a more comprehensive understanding of the local and global implications of climate change. Additionally, the progression in depth observed in the PMMs, with five students achieving higher levels of sophistication, underscores the potential of narrative-driven learning to promote critical thinking, particularly within games, which, like the real world, are systems. The greater sophistication evidenced in the students’ PMMs suggests that creating a coherent world for the story to take place may have encouraged students to better understand the relationship among causes and contributors to climate change.

Table 2 Predominant concepts displayed on PMMs

Climate change concept	Pre-PMMs	Pre- + Post-PMMs
Ecosystems impacted	5 students (41.7%)	8 students (66.7%)
Temperature affected	8 students (66.7%)	11 students (91.7%)
Natural disasters and extreme events	4 students (33.3%)	9 students (75.0%)
Caused by humans	6 students (50.0%)	9 students (75.0%)
Has direct effect on humans	2 students (16.7%)	7 students (58.3%)

Overall, these findings contribute to our understanding of how designing XR games can affect creators, particularly when the creation process occurs in a collaborative environment that promotes ongoing dialogue.

The program's interdisciplinary structure, blending narrative storytelling with technical design, effectively engaged students and fostered learning. Future programs could build on this approach, incorporating real-world challenges and emphasizing youth-driven, collaborative projects to enhance STEM engagement and climate literacy. By combining technical and creative processes, programs like *Make Games, Save the Planet* can deepen students' understanding of complex topics like climate change and empower them to see themselves as active contributors to addressing global challenges.

Finally, while this study provides insight into the conceptual growth of participants, a few limitations should be noted. First, the sample size was small ($n=12$), which limits the generalizability of the findings. Second, all participants were part of a single program, and there was no control group for comparison. Third, while PMMs can reveal conceptual development, they do not necessarily capture student misconceptions. In our analysis, only scientifically accurate responses were recorded and coded; ideas that were irrelevant or factually inaccurate were not included. Future research might explore larger, more diverse populations and investigate long-term retention of knowledge gained through similar programs. Additionally, examining the specific contributions of narrative design versus technical skill-building could provide further insights into how different elements of the program influence learning outcomes.

Author Contribution Eugene Judson: conceptualization, methodology, data collection and analysis, writing. Rae Ostman: conceptualization, data collection, writing. Nicholas Weller: conceptualization, data collection, data analysis.

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Data Availability Personal meaning maps and resulting data from this study are available from the authors upon reasonable request.

Declarations

Ethics Approval This study entailed the involvement of human subjects and was conducted in accordance with ethical standards, which encompassed the principles of informed consent and approval from an ethics committee.

Consent to Participate The participants in this study were under the age of 18. Therefore, consent was obtained from their parents. Additionally, all participants agreed to participate through IRB-approved informed assent procedures.

Consent for Publication By submitting this manuscript for publication, we give our consent for its publication in the *Journal of Science Education and Technology*.

Competing interests The authors declare no competing interests.

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