Using Playable Fictions and Board Game Design to Teach Climate Change in a Middle School Science Classroom

Kaylee Laub and Earl Aguilera

The authors argue that playable fictions and analog game design can be an effective way to engage students in discussions about climate change and related scientific areas of exploration. They offer the example of a middle school climate science education unit grounded in the design, analysis, and play of board games and card games based on a study of middle school students in a workshop they conducted. They aim to help guide and inspire educators interested in the complex thinking involved in structured play. **Key words:** board games; game design; learning play; playful learning; tabletop games

As Mark Windschitl (2023) writes, "It is no longer an exaggeration to point out that the children sitting in front of you belong to the last generation capable of reversing the climate crisis." (10). The climate crisis is an unprecedented challenge that demands immediate actions, including innovative approaches that will empower and prepare the next generation with the skills to understand and address it. However, integrating complex issues like climate change into middle school science education in a way that is engaging, accessible, and impactful remains a pedagogical challenge (Bhattacharya et al. 2020). As a response to this urgent reality, we describe a unit of study we used in a middle school science classroom that we developed to engage and teach learners about climate change through analog game design.

In developing and implementing this unit, we were specifically interested in positioning students as designers of what we call "playable fictions" about the impact of human activities on earth's natural systems (Barab et al. 2011). For us, the term describes thematic or narrative games that use the design of rule systems, emergent player relationships, and the aesthetic experiences of play to immerse participants in speculation about alternative realities—be they fantastic, otherworldly, or realistically divergent futures not far from our pres-

American Journal of Play, volume 17, number 3 © 2025 The Strong
Contact Kaylee Laub at kayleelaub@ucsb.edu

ent reality. We employed analog game design—which includes board games, card games, and other genres of nondigital games—as the vehicle for engaging students in this approach to teaching climate change topics. However, as we discuss, a pedagogy informed by playable fictions inspired other aspects of our lesson design. Recognizing that such approaches must be personalized and responsive to different contexts of implementation, we hope to provide enough description of the experience to inspire others interested in experimenting with similar approaches.

The Challenge of Teaching Climate Change in Schools

There have been shifts in educational policies and curricula that bring attention to the impact of humans on climate change. One such change in 2013 reflects the development of a set of standards called the Next Generation Science Standards (NGSS): A multistate effort undertaken in the United States to reestablish benchmarks for science learning in kindergarten through twelfth grade (K–12). The publication of the NGSS marked the first time in U.S. history that science standards addressed anthropogenic climate change and was first introduced in the middle school grades (American Meteorological Society 2013; National Research Council 2012). Despite the educational policies and curricula shift, not all states have formally adopted the NGSS. The states that have not integrated the NGSS, especially the standards that address anthropogenic climate change, have not done so primarily because climate change became a topic of political debates, which has heightened the spread of disinformation and cast doubt on the scientific evidence and consensus in the scientific community (Windschitl 2023; Worth 2021). The spread of disinformation and political tensions has spilled into education, where providing students with factual information and opportunities to take action have turned classrooms into battlegrounds (Worth 2021).

A Climate Literacy and Energy Awareness Network survey found that less than 3 percent of free online lesson plans and resources about climate change were acceptable for school use and that the rest were outdated or scientifically flawed (Worth 2021). The available resources online present a challenge for teachers wanting to address anthropogenic climate change. These educational materials and textbooks are misleading and use language that communicates uncertainty about climate change. Also, many of the resources concerning cli-

mate change are decontextualized and can feel far removed from students' lives. They are often framed as problem centered without offering students the opportunity to reimagine solutions. Finally, they involve complex systems, which may be challenging for teachers to teach and for students to conceptualize.

Educators are often positioned as trusted messengers essential to presenting factual information for multiple generations of students. Regarding anthropogenic climate change issues, teachers can explore different perspectives, such as non-Western views, on climate change and allow students to envision multiple possible futures (Windschitl 2023). Although climate change denialism, in its various flavors, has been a documented educational challenge for decades, the recent and rapid spreading of climate disinformation via digital media seems to have added greater urgency to the role of education concerning these topics. With such serious stakes established, we should pause here to discuss why the concept of playable fictions is so central to our approach to addressing these challenges.

Playable Fictions and Game-Based Learning

As we have established, playable fictions is a term used to describe thematic or narrative games that use the design of rule systems, emergent player relationships, and the aesthetic experiences of play to immerse participants in speculation about alternative realities (Barab et al. 2011). By using "playable," within this conceptualization, we mean to emphasize the role of active player participation, immersion, exploration, and improvisation. This helps distinguish playable fictions from genres such as novels, films, and television—what Gee (2007) refers to as more passive in nature. The pluralism of the term "fictions" highlights the various realities that participants are positioned to explore, such as in choose-your-own-adventure books, tabletop role-playing games like Dungeons & Dragons, and their digital descendants played on computers and video game consoles.

Playable fictions might be distinguished from more abstract games, such as *Tetris*, chess, or tag, in which the game play itself is the focus of the experience. In playable fictions, the story lines of games can provide learning environments in which students grapple with concepts and emotions that may be challenging and conflicting but that lead to students fostering deeper understandings of complex topics. As Barab and her colleagues (Barab et al. 2011) argue, the fictionalization

of game play affords opportunities for students to engage in issues that have "political sensitivity, ethical subjectivity, and interpretive contestation" (318) without undermining empirical evidence. Although Barab and colleagues focus on computer games, narratively driven analog games like Sleeping Gods, which positions players as crew members on a steamship, help expand such experiences beyond the digital. Recently, the board game Daybreak by Matt Leacock leverages the idea of playable fictions in our area of interest by positioning players as a global team combating climate change. And while scholarship invoking the term playable fictions emphasizes the role of game play, the work of Kafai and Burke (2015) suggests that students also gain a greater understanding of complex issues when they are positioned as game designers. We integrated the concept of playable fictions into our workshop on various levels, but perhaps most notably in positioning students as the creators of such fictions in their board game design.

In our view, teaching with playable fictions fits into a broader body of approaches collectively known as game-based learning (Aguilera and de Roock 2022). These approaches include facilitating learning through commercial games not initially designed for teaching (e.g., Lee and Probert 2010), as well as so-called "serious games" designed to address very specific topics and create particular learning experiences (e.g., JafariNaimi and Meyers 2015). Beyond the academic or developmental outcomes that often became the focus of discussions about game-based learning, such approaches appear to affect players' social identities, community participation, and even familial relations (Siyahhan and Gee 2016). Although we did care about teaching the content of climate change and aligning it with the standards of teaching science, we were perhaps most interested in encouraging students to make meaning of the complex relationships between humans and the natural systems of the planet. With this framing in mind, we turn to an overview of the context of our teaching and the science standards we were expected to adhere to before moving to a fuller discussion of the workshop's design, implementation, and outcomes.

Context and Participants

We presented our unit of study to middle school students in an eighth-grade science class as a three-week workshop in which we challenged students to create an analog game illustrating one aspect of the impact of humans on earth's

natural systems. Kaylee Laub facilitated this workshop as a middle-school science teacher who attained her master of arts in teaching with a focus on multicultural and social justice education. She is also pursuing a doctorate in science education. Earl Aguilera cofacilitated the workshop as a scholar of games studies, a teacher educator, and a researcher of learning. Together, we discuss the design, implementation, and experience of the workshop from our professional and scholarly perspectives but also as ourselves participants and enthusiasts within video gaming and board gaming affinity spaces.

The public middle school at which Laub worked during this project serves seventh- and eighth-grade students in a suburban area of the western United States. The school's student demographics include an ethnoracial breakdown of 44 percent White, 36 percent Hispanic or Latino, 4 percent Hmong, 4 percent Black or African American, 3 percent Filipino, 3 percent Asian Indian, 1 percent American Indian or Native Alaskan, 1 percent Cambodian, 1 percent Chinese, 1 percent Korean, 1 percent Laotian, 1 percent other Asian ethnicities, and 1 percent other Pacific Islander ethnicities.

There were 149 eighth-grade science students across five class periods who participated in the game design workshop. Students worked in small groups of about three to four students for a total of thirty-eight participating groups. Just under half (45.6 percent) of the students identify as female. The students in Laub's science classes have also been classified according to the following programs: fifteen have resource specialized plans (RSPs or 504s), which are individualized accommodation learning plans for students with disabilities, and six are English Language students. Understanding the diverse needs and backgrounds of the students was important because it informed the development of our instructional approach.

Workshop Design and Implementation

We designed and implemented this project as a three-week unit in Laub's middle school science education classroom near the end of the academic year. Broadly speaking, we divided our time with students, which occurred in the existing scheduled science blocks, or two-hour periods, that defined Laub's teaching day, into three broad chunks: science minilessons, game design minilessons, and game design work time (see figure 1). All five class sections (labeled as periods 1, 2, 3, 4, and 7) were scheduled to meet on Mondays. Students in periods 1, 3,

	Monday (50 minutes)	Tuesday/Wednesday (115 minutes)	Thursday/Friday (115 minutes)
Week 1	Project Introduction	California wildfires What's your game about? Design time!	Air quality in the Central Valley How do we play your game? Design time!
Week 2	Game inspiration	Water quality and access What is needed to play your game? Design time!	Butterfly migration patterns Fine-tuning for fun and challenge Design time!
Week 3	Final work time	Game testing day 1/2	Game testing day 2/2 Exchange feedback and debrief

Figure 1. Three-week lesson plan

and 7 were scheduled to meet on Tuesdays and Thursdays, and periods 2 and 4 were scheduled to meet during Wednesday and Friday sessions.

Minilessons on Science Concepts

Importantly, it was not simply the presence of games and a game design project that characterized our pedagogical approach—even our science lessons themselves were tinged with what Peters and Swadener (2018) refer to as an "ethos of play" (722). In other words, we grounded early-stage sketches of our lesson cycles in local issues and science education standards frameworks, and we tended to plan our day-to-day lessons to center aspects of engagement, interactivity, and enjoyment, even as we tackled issues of climate urgency.

One of the first topics we addressed with students explored the human activities that have led to increased numbers of wildfires, an issue of concern in regional and statewide news. Taking inspiration from trivia-style board games, we modeled our lesson's visual presentation and instructional sequence as a question-and-answer session involving flipping digital cards to reveal answers as students volunteered to answer questions. These flip cards not only explored

the causes of wildfires but also highlighted Indigenous traditional ecological knowledge (ITEK) perspectives on disaster mitigation that had historically been marginalized within the "fire suppression" framings that have characterized Western conceptions of fire science (figure 2). Although we left off the scoring mechanisms and points-based systems typical of such games (and schooling in general), this was our first foray into a play-inspired design for our daily minilessons.

Enjoying the interactive exchanges we had with students during this first lesson cycle, we adopted a similar approach to the topic of local air quality. Shifting away from classic board games, we instead drew inspiration from social games, such as Two Truths and a Lie. Games that fall further toward the spectrum of social games do not necessarily require intensive usage of designed and published materials, but instead can be played even with player-improvised materials, because the emphasis is on social interaction. Using this approach, our lesson presentation offered three claims about air pollution—one of them being unsupported by scientific evidence—and invited students to deduce the supported from the unsupported claims. In hindsight, we also realized that such an approach lends itself to curated debunkings of unscientific claims that become circulated in social media to the detriment of society. When learning

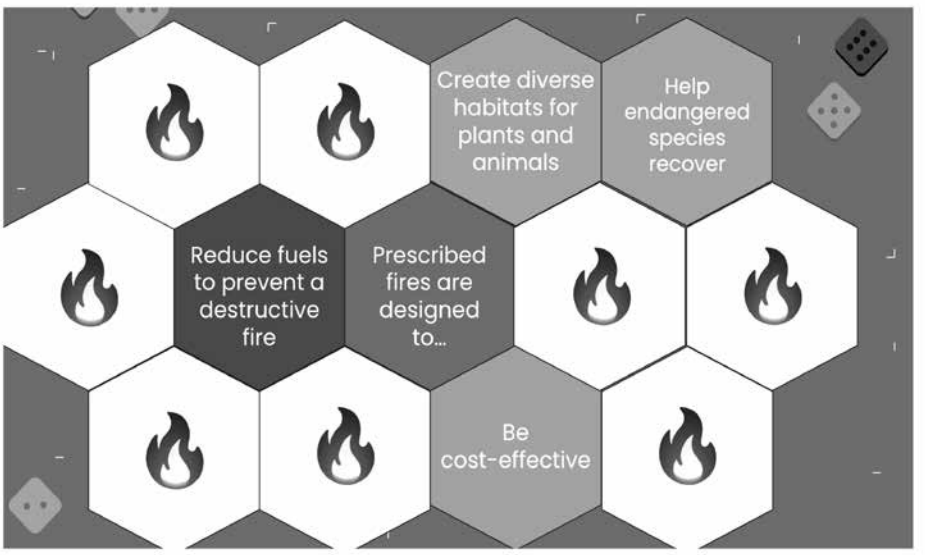

Figure 2. Flip cards about fire science

Figure 3. Air quality action card

about local air quality, we also presented actions students can take through a character action card, which also provides students with ideas for their own game design (See figure 3).

When we presented water quality and access, we offered the information through a digital board game, which was integrated into our slides. The information on water quality and access we embedded in the digital board game based on the spaces on which the players landed. We selected four students from different groups to play in a digital board game presentation about water quality and access, mimicking the roll-and-move mechanics of traditional American board games. Each player moved along the digital board game, and depending on the tile on which they landed, they would be presented with the game action that affected them as a direct consequence of the game, while the backside of the action provided the factual science information related to the game action (see figure 4). The top illustration appears when the student lands on a board tile piece, and the bottom illustration appears on the backside of the game action.

Finally, we addressed the topic of butterfly migration patterns across our local region—another phenomenon affected by shifts in climate. In our lesson planning, we took inspiration from "choose your own adventure" (CYOA)

Figure 4. Digital board game tile action

media, a playable fiction that initially manifested as children's game books in which readers were prompted to make choices concerning how a narrative should progress, and then we instructed them to turn to the pages of the book that aligned with their choices. Eventually, these printed texts inspired hypertext adventure games published on the internet and later developed into more visually oriented digital games. For our context, we developed a simple CYOA-style narrative placing students in the role of butterflies trying to migrate thousands

Figure 5. Choose your own adventure narrative for Monarch butterfly

of miles toward Mexico safely. Some of our visuals are presented in figure 5.

We offer these illustrations to emphasize that our approach to play-based science education was holistic, touching on aspects of pedagogy from assessment to lesson design to our everyday interactions with students. While some promotion of game-based learning refers to the inclusion of one specific element or another, we feel that an overarching ethos of playfulness was a more accurate description of our approach.

Minilessons on Game Design

After our science minilessons, which were scheduled to last about twenty minutes of the total 115-minute block periods, we switched places so that Aguilera could lead lessons in game design. While these lessons drew in part from his work on a prior National Science Foundation–funded project on children's board game design in public library programs, we emphasized game design as a specific discipline. This came in contrast to the more general design thinking process popularized by Stanford's Hasso Plattner Institute of Design (Kessner et al. 2021).

And so, alongside their science lessons, our students also engaged in minilessons concerning various game design elements to support their own board game creation. Our workshops modeled the creative processes of published game designers. In *The Art of Game Design,* from which we drew heavy inspiration, Schell (2008) describes a series of lenses for examining games and the various

Game Title	Designer/ Developer	Description
Among Us	Innersloth (2018)	Players work together as crewmates to complete tasks on a spaceship while trying to identify and eliminate an imposter(s) sabotaging their mission.
Betrayal at the House on the Hill	Glassco et al. (2004)	Players flip tiles to explore a haunted mansion until one player turns a traitor and must be overcome.
Cards Against Humanity	Dillon et al. (2009)	Players use humorous and absurd responses to fill in the blanks of prompts to create the funniest combinations in this adult.
Fortnite Battle Royale	Epic Games (2017)	An online multiplayer game where players fight to be the last person standing, building fortifications and collecting resources.
Mysterium	Nevskiy & Sidorenko (2015)	Players act as psychics to solve a murder mystery by uncovering the culprit, location, and weapon, interpreting clues from a silent ghost (another player),
One Night Ultimate Werewolf	Alspach & Okui (2014)	A social deduction game in which everyone takes on the role of one of a dozen different characters, trying to decide who has infiltrated as a werewolf.
Pandemic	Leacock (2008)	Players work together to prevent global outbreaks and find cures for diseases that threaten humanity.
Photosynthesis	Hach (2017)	Players plant seeds, grow trees, and compete to dominate a small forest ecosystem.
Plague Inc.: The Board Game	Vaughan (2017)	Players act as diseases, battling one another to infect and wipe out humanity.
Ravine	Sisson (2017)	Players stranded on an island after a plane crash work together to gather resources, manage health, and survive.
Spirit Island	Reuss (2017)	Players take on the role of powerful spirits, cooperatively defending their island from colonizing invaders.
Resistance	Eskridge (2009)	Players form teams to complete missions, with a red team operating as undercover spies seeking a blue team's efforts.
The Settlers of Catan	Teuber (1995)	Players compete to earn the most victory points in the land of Catan by collecting resources and building settlements, roads, and cities.

Figure 6. Commercial game glossary

elements that comprise them. We selected and simplified the presentation of some of these game design lenses, drawing on Schell's overarching game design tetrad of story, aesthetics, mechanics, and technologies.

Early in the workshop, we invited students to brainstorm their climate change topic using the element of a game theme and aligning with the lens of a player goal. We prompted students to think what their players would be trying to accomplish within the context of their thematic game. By playing games in class and dissecting game examples together, students experimented with the various actions players could take to achieve their goals, a lens that Schell refers to as game mechanics. Lastly, because we decided to frame board games as multimodal experiences, we asked students to think through the materials they would need to play (and therefore create), which falls broadly under Schell's concepts of aesthetics and technology. As teachers of both the science and game design lessons, we distributed these lessons across a unit of instruction focused on the effects of humans on earth's natural systems (again, see figure 1). We illustrated each of these game design lenses with examples from commercially published board games.

To consider aspects of the game theme, we offered the games Pandemic (disaster mitigation), Ravine (island survival), and Monopoly (real estate). (For a full list of commercial game descriptions mentioned in this article, see figure 6.) As related to this conversation, we also asked students to speculate about their game's concepts, which we broadly connected to common discussions of genre. We exemplified this idea with the card game Go Fish (set collection), the video game *Fortnite* (free-for-all competitive shooter), and the board game Resistance (social deduction). Harkening back to our butterfly migration lesson, we also invited students to consider the perspectives taken on by players, offering pairs of games as examples. We juxtaposed Settlers of Catan with Spirit Island, the latter of which positions players as supernatural protectors of an island fighting against invading colonizers. We also juxtaposed Pandemic with Plague Inc., the latter of which positions a player in the role of a disease seeking to spread itself across the globe.

We addressed the idea of player goals and game mechanics together because it made sense to us that students should be simultaneously thinking about what their players aimed for and the specific means players could pursue to achieve their goals. We offered the example of Betrayal at the House on the Hill to illustrate that games could have asymmetrical goals, with one player pitted against the others for survival. We broke down game mechanics into the components of player actions (such as ship maintenance tasks, calling meetings, and accusing

an impostor in *Among Us*) and the rules that constrained these actions (such as the nonverbal clue giving in the game Mysterium).

We used a guiding question ("What does your game need?") to organize the space, to establish the components, and to clarity the subtopics for our third game design minilesson. In addition to exploring the games we had previously introduced, we also included the example of Photosynthesis, which included the game components of cardboard trees and a sun that moved around a gameboard to shine its light. Even materials such as a simple deck of fifty-two cards proved helpful in illustrating the importance of clarity in game design.

Lastly, we offered a minilesson in the fine tuning of their game designs by thinking about relationships between several of Schell's game design lenses. We discussed the relationship between skill and chance through the examples of chess (pure skill) and Sorry! (pure chance). We discussed the ways that time constraints, such as those in Mysterium, could add tension to an experience, while games like Monopoly dissipated tension over time as one player became dominant. Finally, we explored concepts of challenge and balance through the social deduction games Resistance (in which the game could become unbalanced and lean toward louder players) and One Night Ultimate Werewolf (which balanced talking time more evenly).

Figure 7. Examples of game analysis questions

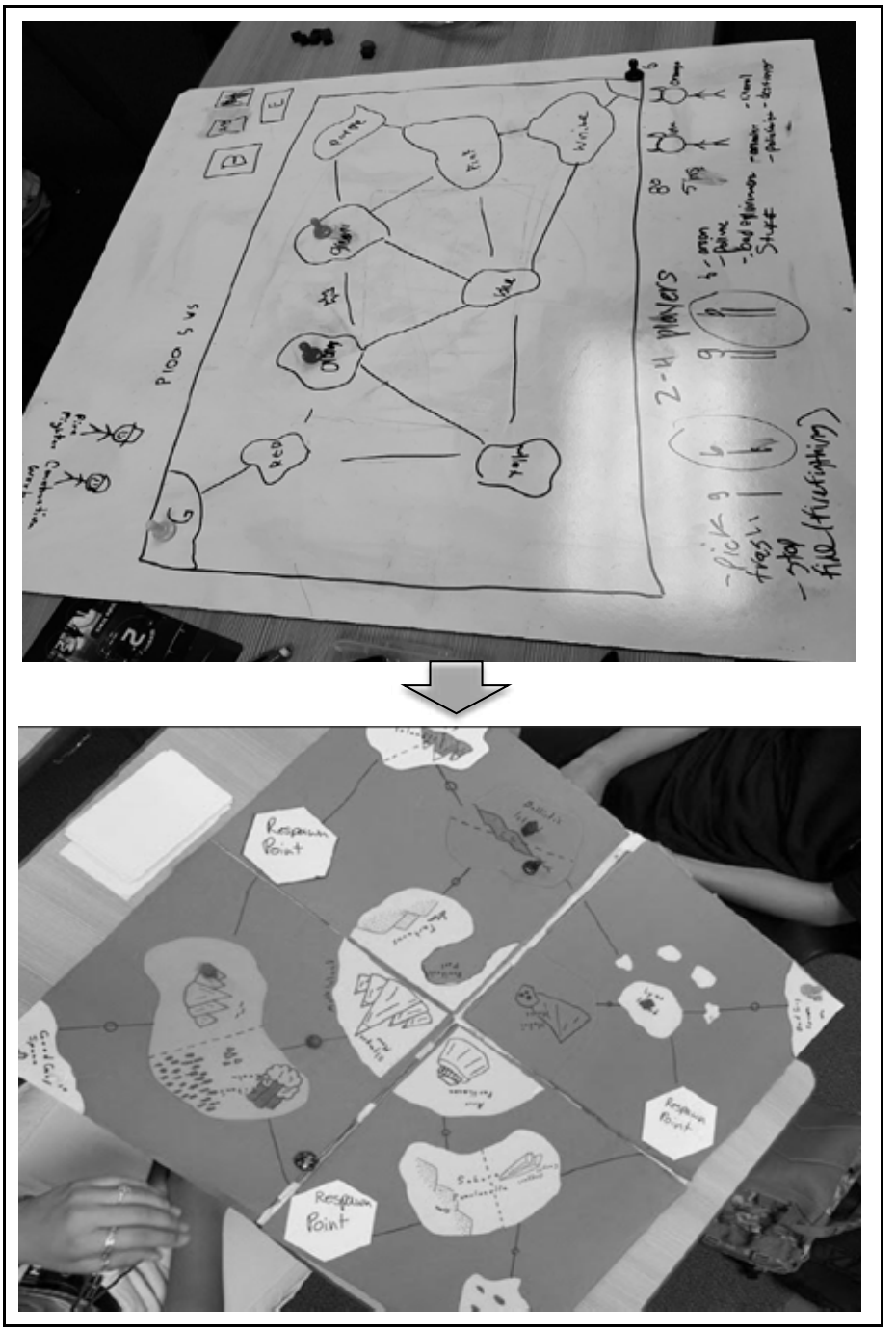

Figure 8. Students' game board model in progress

Our hope was that these examples and analyses of game design elements (see figure 7), combined with prior knowledge students brought to the classroom based on personal experience, would help them ideate, prototype, and test game ideas of their own.

Game Design Time and Play Testing

After our science lessons and game design lessons, we then offered students dedicated blocks of design time during each class session, in which they engaged in essential design practices, brainstorming game rules (ideation), creating testable models (prototyping), and play testing to refine their game ideas. The progression of how students engaged in these design processes can be seen in figure 8. The top image represents the initial modeling process, where students were brainstorming ideas. The bottom image represents their final model, which was this group's final board game prototype. Although we encouraged students to focus on the areas outlined in figure 7 as we transitioned to each of these sessions, we did not intervene in student group discussions if we noticed they were drifting back and forth between design phases. This was informed by Kessner and colleagues' (Kessner et al. 2021) findings about the iterative and recursive nature of the design process in real-world settings.

We scheduled the final block periods of each class (the last week of the workshop) for students to trade their games with another group who then tested the play. Although we did have students draft written rules for each of their games, we also asked that one person from each group teach their game to another group. The student representative for each group rotated as the games were traded around so that every student had the chance to play something made by another group. We invited the students now positioned as play testers to offer each other feedback or to ask questions about the games their classmates made. Again, we provided students with templates and sentence starters for offering feedback but stepped back to allow them to comment on the areas they found most salient.

For us, as both educators and game enthusiasts, the most important assessment students could receive was observing the experience of their play testers and listening to their comments. However, because—within formal educational spaces—the term "assessment" has become synonymous with teacher-centered evaluations of student work, we now discuss our stance on assessment and the outcomes of the workshop overall.

Workshop Outcomes and Assessments

Discussions of assessment have become a reflex response to us as authors involved in teaching and teacher education; the term almost invariably follows conversations about teaching in the circles in which we are typically engaged. However, within the overlapping scholarship of play studies and game studies, assessment can become similarly taken for granted. Within gaming spaces, assessment can become invisible because of the assumption that virtually every game has some object or goal (Tekinbas and Zimmerman 2003). Whether we look at a degree of progress toward that goal (e.g., a win, a loss, or something in between) or the question of subjective experience (Did you have fun?), we are conducting a kind of assessment of the player, the experience, the game design, or some combination of these. And while certain perspectives center play as an intrinsic motivator unto itself, rather than an externalized goal such as winning, developmental discourses often position play as a means toward more fully realizing an individual's capacities—or questions of how to assess such development (Henricks 2020).

Because the context of this game workshop occurred in a formal classroom setting, Laub, the certificated teacher of record, was required to cover state standards and assess students' understanding of environmental principles and concepts. However, the timing of the lesson occurred toward the end of the school year after students completed their state science assessment, which freed us from some of the constraints of standardization and how we would traditionally assess students. Bringing to bear our own lenses about the complexities of assessment and its potential to undermine the students' experiences with the subject at hand, we intentionally moved away from conventional regimes of psychometric measurement. In the third week of the project, we invited students to play test other groups' games. Embracing our roles as authority figures within the game of schooling, we set expectations about how to provide productive feedback and critique while affirming what the students learned and liked about each game they played.

While the students' games were not perfect, the primary focus for our assessment was their conceptual understanding of specific topics and the ways they chose to represent them in their games, which included topics like oceanic pollution, wildfire spread, and air quality. Specifically, we assessed how students could transfer complex scientific concepts into a playable format, which ultimately showcased the systematic processes and cause-and-effect nature of

climate change and which was afforded through the game design process.

In summary, we conceived of assessment through an inquiry paradigm in which teachers were not considered to be test administrators with all the right answers but instead served to document experiences of students who were positioned as active creators of knowledge (Serafini, 2000). This shift from traditional forms of assessment allowed us to value the creative and reflective aspects of the learning process and to offer a more heterogeneous view of students' understanding of complex and real-world topics like climate change.

The Students' Games

In line with our expectations for the students as novice game designers, the board game prototypes they produced represented their wide range of background experience, design practice, and understanding of the science concepts discussed. The games that students developed about climate change drew from ideas related to war, pop culture, fantasy, and trivia, to name a few. Some students used game mechanics such as area control to position players as factions competing to decide the fate of a forest. Others made games connected directly to our science minilessons, centering on issues of wildfires in our state. Many students also invested time creating art for their board game boxes, which we purchased from a local mail store. In this section of the article, we highlight a few examples of student games to demonstrate the range of possibilities educators might expect when implementing or building on approaches such as ours.

Cards That Save Humanity

We found ourselves fascinated by some of the game designs our students created. In some cases, it was clear their work took inspiration from some established game like Cards Against Humanity (fill-in-the-blank card game), but with a climate-science twist. For example, in one group, four students created a game titled Cards That Save Humanity, a game in which players take on the persona of professionals, some of them in the science, technology, engineering, and mathematics (STEM) fields (see figure 9). These six character cards showcased individuals of different genders, races, and sexualities. Much like the game of Cards Against Humanity, one player is considered the judge who poses a climate-related problem, and the other players have to play the cards in their hand that best solve the problem. Through argumentation and persuasion, each player

Figure 9. Character cards from students' science game

presents a case to the judge for that round to determine why any given card should be selected as the best solution.

In Cards That Save Humanity, we see student agency and creativity reflected in a game design in which students created "character cards" for players that included clear delineations of the characters' gender and sexual identities. Their designs speculate about a future in which those at the front lines of the climate crisis represented a much more diverse spectrum of identities than has been historically associated with STEM fields. Though sometimes sidelined as inappropriate topics for discussion in science classes, issues of race, gender, and sexuality are becoming increasingly unavoidable in schooling and important to discuss explicitly in light of oppressive policy trends in public schools. This group, in particular, used their creative space to engage in conversations that meaningfully integrated content knowledge, creative design, identity development, and civic participation for adolescents. Ultimately, they crafted a playable fiction in which historically marginalized individuals prove central to the fight against climate catastrophe.

Biome Wars

The objective of Biome Wars is to win the war with the least amount of ruined environment. A group of three students developed this game in which players find themselves in either a mountain, forest, desert, or grassland biome (see figure 10). Players draw event cards during their turn and must decide whether they are going to invade or restore spaces. Invasions occur in two turns. Players can transfer troops to a targeted space in the first turn, and during the second turn the invasion occurs. Invasions come if your biome has more troops than the biome you are trying to invade. Restoring land occurs when a player rolls an icosahedron (a twenty-sided die) and lands a fifteen or higher. The event cards that the students developed for the game objective represent their understanding of the impact of humans on the environment. Some of the event cards that affect each biome were

> Grassfires have started at A2 (located in the grassland biome section of the board) because of the gunfire; all troops there are killed.
>
> Because of climate change, the snow on the mountains is melting earlier in the season, the troops there are defenseless in the sludge, and any other troops can take those bases despite the numbers.

> Climate change has increased temperatures in the desert. Roll to see if the owner is able to pump in enough water to keep troops from overheating and watering holes from going dry. Roll a 1–5 (Watering holes go dry. Evacuate troops.) 6–10 (Nothing Happens). 11–20 (Enough water. Troops can stay).
>
> The water supply to the forest has become unhealthy due to pollution, D2 and D3 (both located in the forest biome section of the board).

In the rulebook, students demonstrate their connection to wars and the impact of humans on the environment by providing an interesting fact that

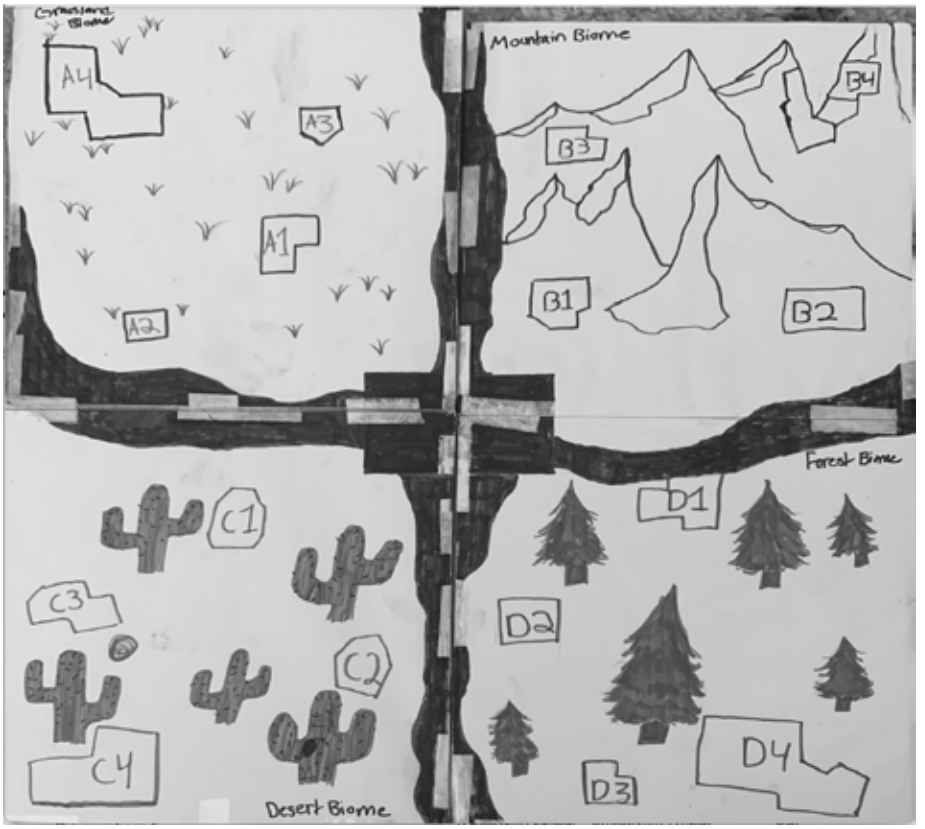

Figure 10. Biome Wars game board

stated, "Did you know that military activities produce large amounts of greenhouse gases which contribute to pollution and climate change?"

For us as teachers and researchers, notable aspects of this design included the centrality of player versus player conflict, which conversations with students indicated were a kind of response to events of global conflict dominating news headlines and entering into everyday discourse. Further evidence of this can be seen in the students' selection of scientific facts included in their game's rulebook, which focused on the contribution of military activity to the ongoing climate crisis. Were we to support the students in further iterating this design, we might consider inviting them to explore alternative relationships between players and to determine how these dynamics might shape the way their game speculates about climate futures.

Air Pollution

Developed by three students, Air Pollution was a board game prototype that exhibited how an understanding of the environmental impact of human activities focused on breathable air quality. The board represented the map of the United States on a scale from the cleanest air to the poorest air quality (see figure 11). Students retrieved this information from a dataset published by the United Health Foundation, which compiles information from public health sources, including the U.S. Centers for Disease Control and Prevention (CDC) and the U.S. Census Bureau (Air Filters Delivered 2022). The board game itself depicts what students perceived to be states that had the cleanest to poorest air quality. They included a meter on the bottom left of the board, which would increase based on the cause cards they created. The cause cards illustrated the impact of humans on the environment, specifically as they attributed to air pollution. Some examples of the causes cards included

> Every gallon of gasoline burned creates about 8,887 grams of carbon dioxide. Add 1,000 to the meter (2 lines up). Use the blue hand to keep track of the levels.

> Every year, container ships plying the world's waterways spew about 1 billion metric tons of carbon dioxide into the air, which is about 3% of all greenhouse gas emissions. Add 1,000 to the meter (2 lines up). Use the blue hand to keep track of the levels.

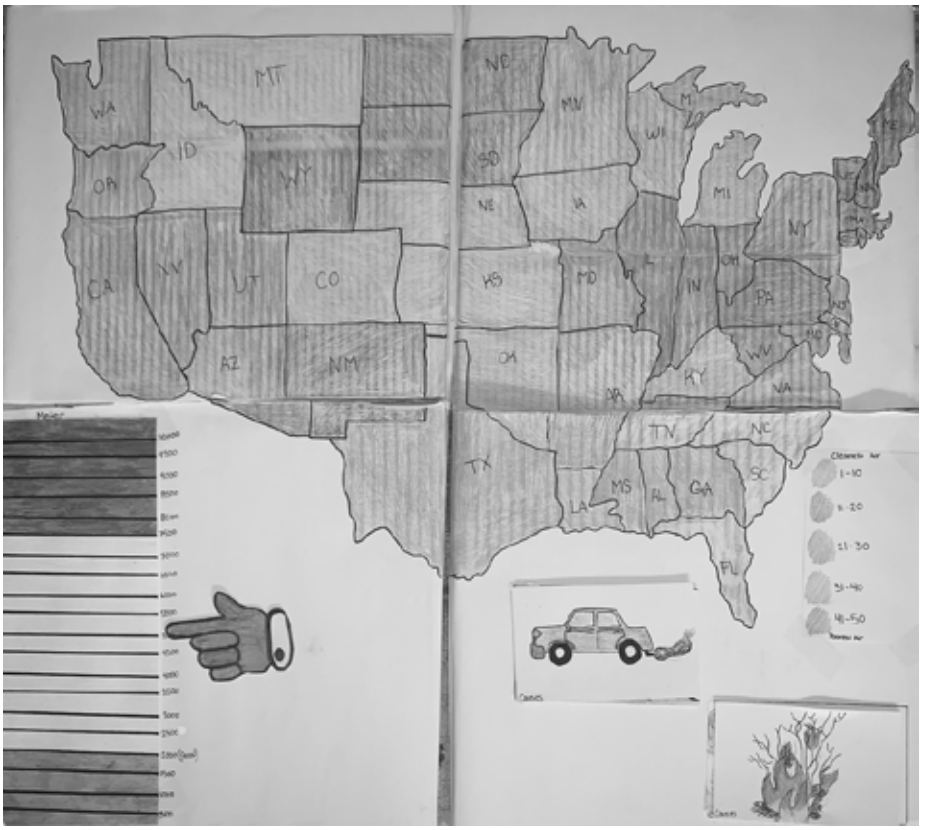

Figure 11. Air pollution game board

This game board's designed features could be interpreted as a student response to our game design lesson on the importance of game materials, as well as the use of game space as a mechanic for play. We see parallels between our lesson on the use of board game space in the commercially produced *Pandemic* board game—with its own indicators of disease severity—and the students' indicators of air quality. Both the commercial model we shared and this student design use a similar "fail state" threshold (marked by the blue hand in the students' design). As teachers, we appreciated the ways students paired the sharing of facts about patterns of industrial pollution with in-game mechanical impacts. Were this workshop taught at the beginning of a school year rather than near the end, we imagine the possibility of further exploring how students might model real-world systems as game mechanics.

Student Responses

We gave students a streamlined rubric to assess other groups' games and an open-ended response to provide specific comments. At the end of the play testing of other groups' games, students were able to review the feedback forms they received from their peers. In the end, each student participated in a final Google form survey, which asked them to reflect on their project experiences and what they had learned. One hundred and thirty-seven students responded when asked on a Likert scale to share how helpful they found the game design process in learning science. Fully 94.2 percent of the students described their participation in the game design process as either a "really helpful" or a "helpful" way to learn science. Additionally, students were asked to share how they felt about the games their groups made. Again, a huge majority, 92.1 percent of the students, either "really liked" or "liked" the games they created.

In an open-ended response, students were asked to share what they learned about the impact of humans on the environment that they did not know before their participation in the game design workshop. We qualitatively coded the students' comments, beginning with open coding to generate initial impressions, axial coding to refine our initial coding ideas, and selective coding to apply our final coding scheme to the data corpus (Saldaña 2021). After organizing our final codes into themes, we settled upon six environmental issues that characterized their responses, which included butterflies, deforestation, earth or environment, ocean, pollution, and wildfires. The responses students had to these environmental issues could be further categorized as general statements of scientific understanding, environmental systems awareness, game design statements that represented their experiences and what they learned throughout the game process, and action statements that demonstrated solution-oriented approaches to the problems presented by climate change. The following responses are examples of what students shared from the survey:

> I learned that electricity power plants contribute to climate change, deforestation is part of the cause for pollution, pesticides in the ground can pollute wells, and I learned so much more than just that so I can't list everything.

> I did not really think about how bad the air quality is in [local city] from the factories and other things until this project. I also didn't

> think about how many fires there were and how they affected [sic] us.
>
> The games had a lot about human impact and taught me how you can solve environmental problems by using games and going through a process to [solve] the problem.

In these responses, we saw how students connected some human activities to the events that drive climate change. In the first statement, the student connected deforestation to pollution, highlighting the cause-and-effect relationship between the impact of human activity and environmental outcomes. This student also provided a concrete example of how pesticides, specifically, pollute drinking water. The second statement illustrated the connections between the impact of human activity and the local area and how wildfires can directly affect the community on a smaller scale. The third statement provided insight into how the game design process encouraged students to think about solutions to some of the negative impacts of human activities.

Although it is beyond the scope of this paper to detail an exhaustive analysis of student responses, these examples illustrate students' initial systems awareness, including of the cause and effect of climate change and actions that can mitigate or adapt to these changes, which were supported through this lesson's game design and play-testing process. Our sense is that our experiences resonate with prior literature about students' mental models of scientific concepts—namely, the finding that the development of strong conceptual understanding takes time, practice, and dedicated effort, even if surface-level understandings may be evident (e.g., Vosnidou and Brewer 1992). A paper dedicated to these efforts might explore how play may allow students to develop critical thinking around climate change and in science education more generally.

We acknowledge the limitations of this approach because it does not mimic objective forms of assessment. However, we did not intend that engaging students in the process of game design and play testing should replace traditional objective-style tests but that it can act as a complement to them. Moreover, it provides an alternative avenue for students to demonstrate understanding while helping make them agents who can play with their own actions to see various alternative outcomes in the games they created, which is a paramount approach when considering ways to address the realities of anthropogenic climate change.

Lessons Learned and Suggestions for Future Implementations

From the perspective of credentialed educators in a formal classroom setting, one of the primary challenges with which we grappled, as we have mentioned earlier, was the temptation to return to standardized assessments of learning. Although we recognized the importance of teaching to the NGSS standards and identifying key criteria for success, we chose to embrace the open-ended nature of the end-of-unit deliverable: a playable board game prototype illustrating some aspect of the impact of humans on earth's systems. Rather than aligning our final grading rubric to the recall of factual knowledge, we found that such an open-ended assessment allowed us to qualitatively understand the strengths and gaps in students' conceptual understanding. For those interested in similar work, we recommend portfolio assessments and presentations of learning (Easton et al. 2014; Simpson and Whitworth 2021).

A second challenge we faced concerned our local context of implementation: a politically conservative, rural school district in which certain interest holders vocally challenged the scientific consensus on issues such as vaccinations and climate change. Conversations with local teachers have helped us understand the value of distinguishing "public controversy" and "scientific controversy" with students. Classrooms can serve as a safe space to encourage students in academic discourse about issues that may be politically, socially, or economically controversial, but on which scientists have a clear consensus (Laub 2022).

Finally, a core challenge that remains central to the entire field of science education is ensuring diversity, equity, and inclusion (DEI) are centered in all of our formal and informal science teaching. For us, addressing this challenge meant that we had to be vigilant throughout our unit design and lesson implementation process about issues of visual representation, knowledge recognition, and varied modes of participation throughout the unit. While we chose to center Indigenous traditional ecological knowledge (ITEK) and celebrate our students' own representations of gender and sexual diversity in STEM, we encourage educators to be mindful of and responsive to the particular DEI issues affecting their students (Laub and Aguliera 2024).

Conclusion

By approaching our lesson on climate change in local and regional contexts

through playable fictions, we ensured our students were able to connect and engage with the issues to determine how humans can mitigate or prevent the negative impact we have on our community ecosystems. Playable fictions also appeared in students' development of their own board games, in which they were able to integrate aspects of climate change into the game mechanics. The board games that students created serve as a form of modeling, which allows students to manipulate, through play, and make complex systems tangible for them to conceptualize. Although we faced challenges during the implementation of this type of lesson, the allowance of game development positioned our students as creators of content rather than just consumers of knowledge. In short, we gave them the space to imagine new worlds and their places within them.

References

Aguilera, Earl, and Roberto de Roock. 2022. "Digital Game-Based Learning: Foundations, Applications, and Critical Issues." In *Oxford Research Encyclopedia of Education*. https://doi.org/10.1093/acrefore/9780190264093.013.1438.

Air Filters Delivered. 2022. "States with the Worst Air Quality," April 1. https://www.airfiltersdelivered.com/blogs/helpful-tips/states-with-worst-air-quality.

American Meteorological Society. 2013. "Climate Science is Core to Science Education," May 23. https://www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/climate-science-is-core-to-science-education/.

Barab, Sasha A., Tyler Dodge, Edward Gentry, Asmalina Saleh, and Patrick Pettyjohn. 2011. "Uganda's Road to Peace May Run through the River of Forgiveness: Designing Playable Fictions to Teach Complex Values." In *Designing Games for Ethics: Models, Techniques, and Frameworks*, edited by Karen Schrier and David Gibson, 312–33. http://doi.org/10.4018/978-1-60960-120-1.ch019.

Bhattacharya, Devarati, Kimberly Carroll Steward, and Cory T. Forbes. 2020. "Empirical Research on K–16 Climate Education: A Systematic Review of the Literature." *Journal of Geoscience Education* 69:223–47. http://doi.org/10.1080/10899995.2020.1838848.

BoardGameGeek, n.d., a. "Betrayal at House on the Hill." https://boardgamegeek.com/boardgame/10547/betrayal-at-house-on-the-hill.

———.n.d., b. "Cards Against Humanity." https://boardgamegeek.com/boardgame/50381/cards-against-humanity.

———. n.d., c. "CATAN." https://boardgamegeek.com/boardgame/13/catan.

———.n.d., d. "Mysterium." https://boardgamegeek.com/boardgame/181304/mysterium.

———. n.d., e. "One Night Ultimate Werewolf." https://boardgamegeek.com/boardgame/147949/one-night-ultimate-werewolf.

———.n.d., f. "Pandemic," https://boardgamegeek.com/boardgame/30549/pandemic.

———. n.d., g. "Photosynthesis." https://boardgamegeek.com/boardgame/218603/photosynthesis.

———. n.d., h. "Plague Inc.: The Board Game." https://boardgamegeek.com/boardgame/195162/plague-inc-the-board-game.

———. n.d., h. "Spirit Island." https://boardgamegeek.com/boardgame/162886/spirit-island.

———. n.d., i. "The Resistance," https://boardgamegeek.com/boardgame/41114/the-resistance.

Easton, Lois Brown, Dan Condon, and Michael Soguero. 2014. "Engaging the Disengaged: How One School Re-Engages Students in Learning." *Teachers College Record* 116:275–301.

Gee, James Paul. 2007. *What Video Games Have to Teach Us about Learning and Literacy*, rev. ed.

Henricks, Thomas S. 2020. "Play Studies: A Brief History." *American Journal of Play* 12:117–55.

JafariNaimi, Nassim, and Eric M. Meyers. 2015. "Collective Intelligence or Group Think? Engaging Participation Patterns in *World Without Oil*." In *CSCW '15: Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, Vancouver, British Columbia, March 14–18. https://doi.org/10.1145/2675133.2675258.

Kafai, Yasmin B., and Quinn Burke. 2015. "Constructionist Gaming: Understanding the Benefits of Making Games for Learning." *Educational Psychologist* 50:313–34.

Kessner, Taylor M., Priyanka Parekh, Earl Aguliera, Luis E. Pérez Cortés, Kelly M. Tran, Sinem Siyahhan, and Elisabeth R. Gee. 2021. "(Design) Thinking Out Loud: Adolescents' Design Talk in a Library Makerspace Tabletop Game Design Camp." *Information and Learning Sciences* 122:651–70.

Laub, Kaylee Allison. 2022. "Leaning into Controversy: Pandemic Conversations in a Science Classroom." *Language Arts* 100:56–58.

Laub, Kaylee Allison, and Earl Aguilera. 2024. "Representations of Race, Gender, and Sexuality in Middle School Students' Game Design Practices," roundtable session, Annual Meeting of the American Educational Research Association, Philadelphia, Pennsylvania, April 11.

Lee, John K., and Jeffrey Probert. 2010. "Civilization III and Whole-Class Play in High School Social Studies." *Journal of Social Studies Research* 34:1–28.

National Research Council of the National Academies. 2012. "Dimension 1: Scientific and Engineering Practices." In *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, 41–82. doi:10.17226/13165.

Peters, Lacey E., and Beth Blue Swadener. 2018. "The Right to Childhood and the Ethos of Play." In *The Cambridge Handbook of Play: Developmental and Disciplinary Perspectives*, edited by Peter K. Smith and Jaipaul L. Roopnarine, 722–42.

Saldaña, Johnny. 2021. *The Coding Manual for Qualitative Researchers*. 4th ed.

Schell, Jesse. 2008. *The Art of Game Design: A Book of Lenses*.

Serafini, Frank. 2000. "Three Paradigms of Assessment: Measurement, Procedure, and

Inquiry." *The Reading Teacher* 54:384–93.
Simpson, Lauren, and Brooke Whitworth. 2021. "Science Portfolios: Embedding the Nature of Science." *The Science Teacher* 88:58–63.
Siyahhan, Sinem, and Elisabeth Gee. 2018. *Families at Play: Connecting and Learning Through Video Games*.
Tekinbas, Katie Salen, and Eric Zimmerman. 2003. *Rules of Play: Game Design Fundamentals*.
VideoGameGeek, n.d., a. *Among Us*. https://videogamegeek.com/videogame/317042/among-us.
———.n.d., b. "Fortnite Battle Royale." https://videogamegeek.com/videogame/135781/fortnite-battle-royale.
Vosniadou, Stella, and William F. Brewer. 1992. "Mental Models of the Earth: A Study of Conceptual Change in Childhood." *Cognitive Psychology* 24:535–85.
Windschitl, Mark. 2023. *Teaching Climate Change: Fostering Understanding, Resilience, and Commitment to Justice*.
Worth, Katie. 2021. *Miseducation: How Climate Change Is Taught in America*.