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# The Design of Embodied Participatory Simulations as a Collaborative Learning Environment

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**Abstract:** Advances in augmented reality, real-time location tracking, and agent-based modeling technologies are converging to create a powerful infrastructure for collective learning. Yet the social conventions that shape how learners will engage in activities using this infrastructure are not well established. In response to this need and opportunity, we involved groups of 9th grade students as designers of group activities in this emerging medium. After inviting them to experience, reflect on, and critique activities that we had previously constructed with this infrastructure, we engaged them with the challenge of designing their own activities, with the goal to support an audience of younger learners in learning and reasoning about issues of sustainability and ecosystem dynamics.

## Introduction and conceptual framework

There is a long history of groups using enactment and role-play to support their collective reasoning about the behavior of complex systems (cf Forrester, 1968; Senge, 1990). Recent research and development work in education has explored how these social practices can be supported by technological infrastructures including agent-based modeling and networking (Wilensky & Stroup, 1999), wearable devices (Brady et al, 2016a, b; Peppler et al, 2010), and augmented reality (Danish et al, 2015; DeLiema et al, 2016). Yet, as this infrastructure emerges, the range of its possible applications in learning activities is under-specified. Is it appropriate to see such environments as supporting *play* (Danish et al, 2015) and *games* (DeLiema et al, 2019)? Or are they more connected with models of participatory *theater* (Boal, 1985)? Or are they forms of *simulation*: *experiments* in which the participant group acts both as the experimenting *observer* and the experiment itself (Forrester, 1968; Resnick & Wilensky, 1998)? We describe an ongoing project to enlist groups of 9th graders to explore these questions of the affordances of activities in these novel environments, by supporting them to *design* such activities for younger students, on chosen topics in sustainability and social-biological systems.

## Theoretical Background

Our project is informed by traditions of design-based research (Cobb et al, 2003), on learning about complex systems; on activity structures to support collective reasoning through shared embodiment (Pierson & Brady, 2020); and on the value of positioning learners as designers (Harel & Papert, 1990). Based upon what we know about how individuals and groups can productively grapple with complex systems with an eye toward making changes in the emergent outcomes of those systems (Hjorth, Brady, & Wilensky, 2018), we structured a study to position groups of young people as designers using novel, augmented reality (AR) technologies to create experiences for groups of *younger* learners, around sustainability topics that were of concern to the designers.

### Reasoning about complexity through agent-based modeling and participatory simulations

The natural and social sciences grapple with complex interacting systems. Moreover, the coupled social-biological systems that are the focus of challenges of sustainability are increasingly connected and nonlinear (Barabasí, 2002). From both cognitive and social perspectives, there can be cause for pessimism about supporting learners to develop intuitions about complexity. Expert-novice studies suggest the two groups often use very different ontologies and schemas about complexity (Larkin et al, 1980). This can lead researchers to suggest student ideas are not highly useful resources in this area (Chi et al 2012). Yet, another research viewpoint argues that many challenges that learners face are related to the challenge of coordinating powerful ideas across two (or more) “levels” of experience and analysis of complex systems. In this view, errors in prediction or interpretation arise when learners mis-apply intuitions that they have developed and found effective at one level of experience, to another level (Wilensky & Resnick, 1999; Sengupta & Wilensky, 2009).

Agent-based modeling (ABM) provides conceptual and technological infrastructures that can enable researchers to study and address challenges associated with complexity. ABM captures a system’s behavior by “growing it” (Epstein & Axtell, 1996) from the behavior of system elements–by identifying the individual “agents” of a system and devising computational rules to describe their actions and interactions. Computational environments then can create many independent agents and "run" them concurrently. This allows modelers to explore connections between the micro-level behaviors of individuals and the macro-level patterns that emerge. Running and refining ABMs enables learners to "debug their systems thinking" by debugging their ABMs.

Participatory Simulations (PartSims) are group-based learning environments in which participants collectively simulate scientific or social systems phenomena by enacting agents in ABMs through coordinated role-play (Brady et al, 2016a; Colella, 2000; Danish et al, 2020; Klopfer, Yoon & Perry, 2005; Resnick & Wilensky, 1998; Wilensky & Stroup, 1999). *Descriptive* PartSims, in which participants enact sets of pre-written roles to observe their emergent consequences, have been the focus of a long tradition of design research in science, mathematics and the social sciences (Wilensky & Rand, 2015; Wilensky & Stroup, 1999).

### Representational supports for collective ideation and problem-solving

However, in many settings—and particularly with issues of sustainability—it is not sufficient or scientifically satisfying to enact one emergent outcome of agent-based rules at the systems level. There is a strong urge to understand not only the range of possible behaviors of a system, but also how agents can exhibit *agency,* and coordinate to achieve emergent outcomes they agree are *more desirable* (Gilligan et al, 2015; Hjorth et al, 2018). We align such efforts to use ABM thinking to envision a better system with Wilensky & Rand's (2015) category of *exploratory* modeling. *Exploratory* Participatory Simulations have connections with a range of activist and advocacy work, such as *companion modeling* (Barreteau, 2003), integrating the co-construction and use of models to support social groups in articulating their practices and goals, and coordinating to achieve them. More broadly, ABM, PartSims and role-playing games have shown potential in developing shared understandings of social-ecological systems to inform proposals for farming practices, water management and policy, and land use (Voinov et al, 2018; Castella, Trung, & Boissau, 2005; Briot, Guyot, & Irving, 2007; Zellner et al, 2012).

Philosophically, exploratory PartSims rest on a belief that, with representational supports, groups of people can reason collectively in ways that are qualitatively different from how they might operate as isolated individuals. This philosophy is grounded in empirical and historical research. For instance, Elinor Ostrom's Nobel Prize-winning work (Ostrom, 1990) analyzed approaches to the "Tragedy of the Commons" dilemma, which was famously outlined by Hardin (1968) as an essentially inevitable social tendency to abuse common-pool resources. In contrast, Ostrom showed that societies have been able to discover and sustain solutions, often by making the operation of the system collectively visible. This belief that collective representations, defined by a social group, can support their coordination and orientation toward a shared vision also links low-tech liberatory practices like Augusto Boal's Theatre of the Oppressed (Boal, 1985) to large-scale pro-social games (McGonigal, 2011), and to futurist hopes that the internet might act as a lever for new forms of democracy (Lèvy, 1999).

### Articulating collective ideas through shared-embodiment activities

PartSims can offer groups "first-person" experiences of complex systems at *two* levels: first-person *singular* ("I") experiences of micro- level agent behavior, and first-person *plural* ("We") experiences of the macro-level systems behavior. As such, they provide entry points to ABM, where learners "dive into" (Ackermann, 1996; Resnick & Wilensky, 1998) phenomena and identify with particular systems elements, while at the same time, as a collective group, they experience embodying the system as a whole (i.e., "stepping out"; Ackermann, 1996). Moreover, ABM and PartSims have a long history of connection with embodiment. The prototypical "turtle" agent was celebrated for its "body-" and "ego-syntonicity" (Papert, 1980), and early PartSims were enacted bodily, even after initial technological supports were added. Yet, as the practice has evolved, many PartSims have become shared virtual affairs, with participants remote-controlling virtual agents.

We have found embodiment carries particular value for exploratory PartSims, enabling emergent choreographies (Solomon et al, 2021) and understandings of the relations among systems elements (Brady, 2021; Brady et al, 2016b; Pierson & Brady, 2020). We have seen how expressivity and inquiry can be fueled by shared physical enactment, drawing inspiration from the performing arts of improvisational dance and theater (Reimers & Brady, 2020; Vogelstein, 2020). In part, the value of embodied enactment comes from the variations in different humans' enactment of "the same" rules (Wagh et al, 2021). Whereas these variations can be seen as liabilities in descriptive modeling, they can be sources of innovation and novel ideas in exploratory modeling contexts.

## Research Problem

The history of computer-supported collaborative learning about complexity, broadly outlined above, has revealed a persistent theme: namely, that with appropriate representational infrastructures, groups can enact systems phenomena together not only for the *descriptive* modeling purpose of understanding the existing dynamics of complex systems, but also for the *exploratory* modeling purpose of organizing to change those dynamics and the emergent behaviors that result. In the context of sustainable social-ecological systems, exploratory modeling connects the natural sciences with political science and sociology. Representational infrastructures serve the dual purpose of capturing known systems dynamics and discovering as-yet unknown solutions as enacted by the participants. While activist work mentioned above (e.g., companion and participatory modeling, and the Theater of the Oppressed) has identified techniques for facilitating such exploratory work, these practices have not yet integrated novel technologies such as AR or location tracking; and they have not been applied systematically to the challenge of engaging learners with complexity and emergence. As learning scientists, we thus have found ourselves at a moment of high potential, and high uncertainty, where our activity design could take a wide range of directions. Considering the *genres* of activity that have inspired prior work, we find that collective enactment activities have been seen as analogous to games, to stories, to experiments, or to theatrical performances, among other possibilities. But what are the affordances of each of these genre models? As part of our own exploration of this problem, we identified an opportunity to pose it to groups of learners as part of a design challenge.

### Learners as designers, and design as a learning environment

Involving learners as designers can offer insights not only into the nature of their knowledge, but also into the relations they establish with the ideas expressed in their designs. Analogously with Harel & Papert's (1990) account of the design of Constructionist environments as a learning environment, involving these groups of learners in the design of embodied AR participatory simulations for sustainability has the promise of illuminating not only the texture of ideas about sustainability and the social-biological systems that the designers found most important, but also the ways they wanted to position their younger clients to relate to these ideas. Moreover, involving learners as designers enables researchers to understand children's perspectives on the activity genres within which they are designing. For Harel & Papert (1990), this illuminated the construct of the *microworld* (Papert, 1980). For us, an emerging research question about what range of experiences the AR technology might be *good for* producing for groups is analogous. As we will show, presenting the technological infrastructure (honestly) as lacking normative expectations for the interactions and genres that it could support, opened a design space for learners to imagine it as being "good for" games of certain kinds; for stories and participatory narratives of certain kinds; and for exploratory social experiments of certain kinds.

### Research Questions

To make progress on this research problem, we formulated the following questions:

- How can we engage groups of youths as designers of embodied AR PartSims, and how do they view the purpose and affordances of the multi-body AR technology as an infrastructure for group activities?
- What aspects of the participant experience do youth designers focus on as pivotal, in their efforts to engage groups of younger learners in learning about and taking action to support sustainability?

## Methods

Our ongoing study involves a group of 26 9th graders from urban public schools in a mid-sized city in the southeastern US. These students are participants in a university-district partnership program, where students from schools across the district meet weekly at the university during the school day for programming that provides access to research experiences in science and math across the high-school years (grades 9-12). At the time of writing, our study has unfolded over two months, with over six hours of design work spread over three sessions. While this paper is focused on the high-level structure and findings of the design enterprise, we describe here the trajectory of the sessions and the data sources we have collected here that have informed our high-level findings.

## Sequence of design workshops

The design segment of the study has comprised three Workshop sessions. In the first Workshop, which lasted 1.5 hours, we told students about the new state of our technology, which we had just used to implement activities for the first time in an area middle school. This technology involves wirelessly trackable wearable tags (affixed to the helmets in Figure 1b, below) allowing participants to be located in the space in real time. They are then represented as avatars on an upfront display, endowed with the look and behavioral rules determined by the activity design (e.g., birds that eat moths in Figure 1a, or moth guardians that lead baby moths to safety in Figure 1c).

We explained the location-tracking technology; and we told them how participants' avatars, computer-controlled characters, and the interaction rules among them could all be represented with student-created art and programmed to do anything the designers wanted. We then invited the 9th graders to participate in the two activities we had recently implemented—one in which they were birds aiming to eat moths, and another in which they were 'moth guardians,' shepherding moths to trees where they might be camouflaged from the predator birds (See Figures 1a-c, below). Finally, we asked them to reflect on their experience, focusing on (a) how the two activities made them feel as they participated in them, and (b) how *they* might design activities using this system to engage middle-schoolers with ideas in sustainability and ecosystems that they found important. After this group discussion, we asked students to reflect individually in written homework on the question of how this technology could be used to create an activity about sustainability for groups of younger students.

**Figure 1**
*Example Embodied AR PartSims of Moths and Birds. Left: Act 1; participants are birds, hunting moths. Center: Middle schoolers enacting Act 1. Right: Act 2; participants are moth guardians, hiding moths on trees.*

The program meets weekly on Mondays, and we arranged our Workshops on an every-other-week schedule, to allow us time to receive and process homework reflections. In preparation for the second Workshop, we analyzed the students' responses, characterizing them along two dimensions. The first dimension was whether they described sustainability scenarios that (a) actively centered social-ecological interactions or (b) foregrounded natural systems, which might be impacted by humans' social activity but were considered on their own terms. The second dimension was how they described the activity. Many used the language of games, but others appeared to us to reference theatrical, narrative, or other genres. Using this categorization, we divided the students into four groups: Human-Involved Game; Human-Involved Other; Nature-Centered Game; and Nature-Centered-Other.

In Workshop 2, which lasted three hours, we broke students up into the four groups above, each led by one researcher (one of the four authors), to brainstorm and act out scenarios and put their individual ideas into conversation. As facilitators, we focused their attention on three questions: "How do you want learners to feel? What do you want them to think about? and What actions do you want them to change as a result of the activity?" Our designers began from their individual ideas, first working in pairs to flesh these out, and then presenting their partner's concepts to the larger working group. Throughout this session, the groups were encouraged to use any means they needed to solidify their ideas and, ultimately, to select one or two to present to another group for feedback. Presentations occurred in work-group-pairs, so that the Human-Involved groups and Nature-Centered groups presented to each other. All four groups responded in very generative ways.

During Workshop 2, we also told the designers that the middle school population they were designing for was a 7$^{th}$ and 8$^{th}$ grade program that met in the same building, which allowed them to approach their "Clients" and ask them any questions that would guide their design. Across the four groups, the designers generated questions for the 7$^{th}$ and 8$^{th}$ graders, which we compiled into a survey. On the Monday between Workshops 2 and 3, we asked for volunteers to represent the class, and three 9$^{th}$ graders helped administer this survey to the Clients.

Students' homework reflections after Workshop 2 carried their design work further and helped us to identify the ideas for further work that they had taken away from the session and presentations to their partner-group. Workshop 3, which lasted two hours, was focused on low-fidelity prototyping of the activities. First, each group staged their activity in a physical space that they constructed as a mockup of the AR enactment space. All rules for actions and interactions had to be represented in their low-fidelity prototype; and in addition to verbal instructions, designers used scraps of paper, masking tape, and surveyor's ribbon to construct props and tokens that served functions that later would be implemented in AR for the final activity. When their run-throughs stabilized, the groups invited their partner-groups to learn their activity and test-play the role of participants. After enacting both groups' activities, the design teams regrouped to debrief and to create a short 'marketing' video to represent the final pre-implementation design. At the time of writing, the author team is building technology prototypes of each of the activities, in preparation for Workshop 4, which will last three hours and involve all groups enacting, reviewing, and identifying revisions for the technology-prototype activities. After this session, we will make refinements to the software based on the designers' revision comments, at which point the activities will be ready for the designers to use in implementation sessions with the 7$^{th}$ and 8$^{th}$ graders, early in 2022.

## Data sources

In all Workshop sessions, learner interactions have been captured with standing video cameras, which provide data for later analysis of the design process using methods of Interaction Analysis (Jordan & Henderson, 1995).

Our goal is to interpret the 9th graders' collective engagement with the design space as they encountered it, thereby to better understand their conceptions of the social-biological systems that their activities foregrounded, and their perceptions of the affordances of the socio-technological infrastructure of embodied AR PartSims.

## Findings

We begin by describing the four groups' final game designs. In each case, this design was one among several candidates, and selecting a single activity to pursue into implementation was both a difficult and revealing process. After describing the four designs, we discuss themes that emerged across the groups related, to our Research Questions, and we indicate our interpretation of their implications for the affordances of embodied AR PartSims.

### The four selected designs

The first group (Human-Involved, Other) created a multi-round activity, where they wanted to evoke different feelings in the participants in different rounds. The first round involved participants as fish in a space where a limited amount of food was present. The designers anticipated that participants would eat rapidly and somewhat competitively. At the end of the round, they aimed to provoke feelings of *betrayal and surprise* by revealing that the food that the players had eaten was actually contaminated with plastic. Therefore the "winner" who ate the most was actually the "loser" in being most negatively impacted. In subsequent rounds, players, now aware that plastics were mingled with their food, would have access to a "health meter" which would change based on what they ate and allow them to figure out which items in the virtual world were safe, and which were not. The designers wanted to see whether participants would share information they gained with others, and if so, how. This activity developed from the designers' wondering whether *fish* might learn over time to distinguish food from plastic, and whether they might pass that knowledge on to other fish. They wanted to use the simulation to reason about the plausibility of this process. In addition, they wondered whether *students* would feel the *need to cooperate or compete*; and they conjectured that the result might be different for different social groups. Thus, they sought to develop a social experiment and exploratory model on *two* coupled levels—among fish and among humans—hoping that human interactions might help them, and their clients, to reason about fish behavior.

The second group (Human-Involved, Game) took a stance in some ways opposite to that of the first group, creating a game to be played from the perspective of different *human* roles—polluters and cleaners—relating to environmental pollution. Initially, they had planned to allow participants to play as a third role, that of fish, but the group determined that taking the perspective of fish would *not* help participants develop a strong sense of human responsibility for the environment. The designers wanted their student clients to *feel guilty* about their role in contributing to environmental pollution, which they reasoned would lead them to care more and to change their actions. They modeled their final activity design on a video game they liked: *Subway Surfer*. Those playing as polluters would throw trash into a body of water, making it harder for the (computer-controlled) fish living there to swim without being hit (and killed) by trash. Other participants would simultaneously play as cleaners, removing trash from the water, in an effort to protect the population of fish as a whole, as well as a particular fish, which was designated as their personal responsibility. Additionally, the designers clarified that their client students needed to play *both* roles in the game, since getting both perspectives was important to both *feeling guilty* and *feeling empowered* to take action.

The third group (Nature-Centered, Game) designed "Fish Game," in which players first play as fish trying to survive in a polluted coral reef environment and then play as humans cleaning up this environment. Playing as fish involves responding to the negative effects of pollution coming from a factory spewing smoke into the air and trash into the ocean. The factory produces a persistent flow of trash that falls into the ocean, cluttering the environment as well as raising the temperature of the air and water, which causes the fish's food source (coral), to bleach. Eventually, the environment becomes so inhospitable that the players are unable to survive. In designing "Fish Game," the group argued strongly that players should *feel the stress* of being an organism living in contaminated surroundings and competing for resources in an environment depleted and polluted by humans. They wanted to provoke these feelings in order to *stimulate concern*, but they also wanted players to *feel empowered and inspired to make a change* by then playing the role of humans who work collectively to (partially) clean up the environment. In Xavier's words, "When they see how hard animals have it trying to find food with pollution, they feel upset but when they help clean up and see all the good effects, they feel excited to help make a difference" (Xavier, 11/15/21).

The fourth group (Nature-Centered, Other) developed "an interactive game that teaches about both a local and global perspective of pollution in bodies of water" (Ehani, 11/15/21). Using both narrative and gameplay elements, "'Joe on a Mission' teaches you what you can do as an average Joe to help the ocean environment," (Walter, 11/15/21). It takes participants into the life of Joe, a 14-year-old boy, as he goes from cleaning his room to responding to the Mayor's call to clean up the lake near his house, and finally to responding to the President's initiative to fight a corporation illegally overfishing in the ocean. The group's primary design concern was for participants to understand issues related to sustainability at both a local and global level. By this they meant (a) the location and scale of issues relating to sustainability—focusing both on settings where participants live (the local lake) and also in settings far away from their direct experience (large oceans), as well as (b) who can make an impact on the environment—focusing both on small groups of individuals and on the larger conflict between activist groups and corporations. They also felt strongly that players needed to be able to make choices, respond to missions, and *feel responsibility* towards the environment. They aimed to highlight the urgency of sustainability issues, to empower players to make a difference by *feeling that they were not alone* in their efforts, and yet wanted to avoid making players feel too guilty. The student designers felt that a big burden of responsibility to fix the planet already weighed heavily on the shoulders of youth in their generation.

## Themes across the groups' designs and design processes

All groups produced an abundance of candidate activity design ideas. And given the variety of topics (ranging among such topics as forest fires, viral spread, herd immunity, and the politics of public policy enforcement), it is remarkable that the final designs all centered on aquatic ecosystems and the impact of human pollution. Beyond this convergence in topic, several common themes also emerged across the groups' designs and design processes.

### The generativity of focusing on participants' feelings

Throughout the Workshop process, our designers drew inspiration and guidance from the feelings they imagined their activity designs would provoke in participants. This began in their verbal discussion of the Moths-and-Birds demonstration activities, where students described hurried feelings of competition when playing Act 1 as birds, and contrasting feelings of responsibility and cooperation when playing Act 2 as moth guardians. The prospect of awakening particular feelings in participants appeared to help designers both to concretize aspects of the activity as shared understandings and to guide strategic design decisions. These anticipated feelings could be negative ones, such as *betrayal* (Group 1), *guilt* (Group 2), or *stress* (Group 3); or they could be positive ones, such as *altruistic information-sharing* (Group 1), *empowerment* to help (Group 2), *care* and *change-making* (Group 3), and *solidarity* in responsibility (Group 4).

In addition to guiding their design work, evoking particular feelings appeared to be a plausible and meaningful outcome for the designers to target for their audience of younger students. While many expressed desires that their clients would change their life actions as a result of participating in the activities, such changes in action were outside of the horizon of design. Focusing on provoking changes of heart and fostering new reasons and ways to care about the environment seemed more accessible to them.

### The importance of perspective-taking and perspective-shifting

The final designs reveal the designers' sense that the *perspectives* that participants take in enacting the system is pivotal to their experience and learning within the activity. For instance, Group 2's insistence that players take on the role of humans only was a principled decision, based on their desire to confront players with the challenge to solve a problem through coordinated human action (changing the relative rates of pollution and cleanup, rather than, for example, improving the fish's skills at dodging trash). And Group 4's use of a narrative where the protagonist crosses levels and scales of environmental activism was designed to cultivate connected feelings of individual empowerment and collective responsibility.

Similarly, moving *between* perspectives was an important design feature and technique. Thus, Group 2 was careful to insist that players needed to experience the roles of *both* polluters and cleaners, to have the understanding of the system they intended. Group 3 imagined that the experience of playing "Fish Game" as fish was a precursor to the care and empowerment they would later experience in the human role. And Group 1 hoped that feelings of betrayal would frame an experiment about collective learning and information sharing as the participants shifted from a perspective of ignorance to one of awareness about the threat of plastics.

### A rich variety in imagined genres of activity.

Although videogames did offer an attractive genre model, designers also expressed interest in activities that spanned or resonated with a range of genres. Group 1's Round 1 was a game, but it set the stage for more open-ended *experimental* explorations of cooperative-competitive dynamics and their implications for collective learning (of humans and fish). Group 4 *narratively* framed a game-like engagement as part of a trajectory of realizing responsibility and impact across scales. And even the explicitly game-oriented activities of Groups 2 and 3 interrupted typical game dynamics in favor of giving participants a feel for particular aspects of the underlying social-biological systems (for Group 2, the interacting *rates* that governed the changing state of pollution; and for Group 3, the way that the experience of an unwinnable game could motivate the playful performance of a *service* role to make positive environmental change).

## Discussion and conclusion

This study illustrates the rich potential of engaging youth as designers of activities that make use of the novel technology infrastructure of embodied AR participatory simulations. 9th grade designers generated a diverse array of ideas for activities in a range of activity genres integrating narrative, experiment, and theatricality with game-like dynamics, producing iterative refinements of their designs by enacting them. They also articulated design intentions: in particular, they aimed to promote affective feelings in their client participants; and they reasoned in principled ways about the impact of perspective-taking and perspective-shifting on learning and engagement.

We argue that engaging students in design challenges like the one described here has particular relevance during the early phases of the life cycle of a technology. As the infrastructure for embodied AR PartSims becomes better established, we anticipate that a kind of "invisibility" will set in: social conventions will stabilize, and the infrastructure itself will become "understood." Though this process will no doubt increase the "reach" and impact of embodied AR PartSim environments, it will also make their interaction dynamics more conventional and routinized. While the technology is still new, participants can envision a wider range of ways to use it to realize desired forms of collaboration and learning. Positioning youth as designers thus enables us not only to investigate their perceptions of the technology, but also to glimpse images of what they imagine collaborative activities could be good for—supporting groups to come together to do more than their members can accomplish individually.

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