Blending Play and Inquiry in Augmented Reality: A Comparison of Playing a Video Game to Playing Within a Participatory Model

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Abstract: Researchers have increasingly demonstrated how technologies such as augmented reality (AR) can leverage embodiment within play to help students use physical movement to explore complex concepts. Using Vygotsky's (1978) notion of play, we examine how two distinct AR environments—rule-based game play and open-ended modeling play—support 1st and 2nd graders' inquiry (N=122) into how matter changes state at the level of microscopic particles. We further use the notion of keys (Goffman, 1974) to examine how the students construct distinct participation frameworks (Goodwin, 1993) within the two activity designs, and how this organization of activity may impact their learning experience. Our analyses show that students within a game-play environment were more oriented towards accomplishing a goal rather than understanding how a system works whereas those in the modeling-play group focused more explicitly on understanding mechanism and process.

Keywords: embodiment, augmented reality, keys, conceptual blending, interaction analysis

Introduction

The exploration of games to support learning has garnered much attention in recent years (Clark, Nelson, Sengupta, Angelo, 2009). Part of the attraction of games for learning is the playfulness, engagement, and risk-taking they engender (Gee, 2007). In particular, researchers have increasingly demonstrated how new technologies such as augmented reality (AR) can leverage embodiment within games to help students use their physical experiences to explore complex concepts (Enyedy, Danish, Delacruz, & Kumar, 2012; Lee, 2015). However, it is not yet clear how the intersection of embodiment and games effectively supports learning (Lindgren, 2015).

Our study aims to examine how two different game-like AR designs that leverage embodiment can support student learning of states of matter and its particulate nature. We examine evidence from an ongoing design-based research project: Science through Technology Enhanced Play (STEP) to highlight distinctions in two related play environments. In both designs, our overall goal is to shape students' experiences of learning about particles through role-play by varying the nature of the rules underlying the activities, the short-term aims of the activity, and the role of narrative in supporting learning. In STEP (Danish, Enyedy, Saleh, Lee, & Andrade, 2015), first- and second-grade students "shrink" down to the size of microscopic particles to investigate liquid, solid, and gas phase changes through collective body movements. First and second graders (6-8 years old, N=122) are assigned to either one of two AR environments: 1) a design that is oriented towards students producing their own models, implicit rules, and a more fluid narrative (**modeling-play**), or 2) one focused on winning as an end state, overt rules, and a fixed narrative (**game-play)**. We believe that both formats are equally effective in supporting learning; indeed, pre-post results indicate that students in both groups perform equally well on assessments of content knowledge. However, our goal is to develop empirically grounded theory that teases apart *how* features of game-play and modeling-play affect the character of student inquiry in ways that impact learning gains and other forms of success that do not appear on typical assessments.

Theoretical framework: Game-play and modeling-play

Vygotsky (1978) observes that there is an imaginary situation and a set of rules in both socio-dramatic play and game play. However, he argues that rule-based games tend to have thin imaginative contexts (e.g. in chess, the pieces do not graphically attack one another), while socio-dramatic play tends to have rich imaginary narratives but more flexible and negotiable rules (e.g. playing at superheroes entails freedom to decide who has specific superpowers). In both cases, Vygotsky notes that the playful context affords children an opportunity to look upon the rules which govern it in a new light, thus exploring those rules and learning about them in ways that are not as intuitive in other contexts. Similarly, Caillois (1955) describes early childhood socio-dramatic play and the playing of games in later childhood as occupying two points along one spectrum. *Paidia* refers to early pretend play without structured rules and *ludus* refers to games with enforced rules.

In our design, we leverage the distinctions highlighted by Vygotsky (1978) and Caillois (1955) to better understand how these instantiate in learning environments. Specifically, we contrast how a win-oriented, more rule-based, and fixed narrative (game-play) engenders qualitatively different approaches to scientific inquiry for students than a more open-ended design in terms of rules, goals, and narrative (modeling-play). We refer to the second design as modeling play because students are engaged in predicting scientific phenomenon based on our computational representation of particle behavior (Schwarz et al., 2009). Our hypothesis is that different levels of structure within these two designs mirror the distinctions between science and engineering mindsets that Schauble and colleagues (1991) noted. Specifically, engineering mindsets (e.g., game-play) are oriented towards accomplishing a goal rather than understanding how a system works. In contrast, scientific mindsets (e.g., modeling-play) focus effort more explicitly on understanding mechanism and process.

Liminal blends

The STEP simulation software, which is the heart of both activities, is designed to support students in constructing liminal blends (Enyedy, Danish, & DeLiema, 2015). Liminal blends incorporate conceptual blending theory (Fauconnier & Turner, 1998) into a larger distributed cognition framework to highlight how individual mental processes intersect with the material and social world. Briefly, conceptual blends occur when learners integrate disparate cognitive resources to reach new conclusions. Liminal blends are a type of conceptual blend where a student fuses her first-person experience with that of an imagined or an inanimate object (e.g. imagining/gesturing being a point on a graph) and moves back and forth between perspectives without making a clear distinction between them. Integrating resources in this way obscures the division between the physical and conceptual, and has been referred to as semiotic fusion (Nemirovsky, Tierney, & Wright, 1998) or liminal worlds (Ochs, Jacoby, & Gonzales, 1996). In such cases, a "blurring" takes place as participants appear to move fluidly between the physical world in one moment and the symbolic world in the next. The emergent properties of the blend support or hinder learning. In the STEP environment, we therefore intentionally develop new virtual resources (e.g., graphical representations) to support this kind of blending.

Research design and methods

The STEP environment (see Figure 1) was designed to support students as they explored and reflected on science content through embodied play. Microsoft Kinect cameras were placed around the classroom to capture student movement, and the STEP software used students' movement to control aspects of a computer simulation of water particles assembling in different states of matter. As 6-12 students moved about the space, each one was assigned a representation in the shape of a particle, and these particles interacted with one another to create solid, liquid, and gas. As the students moved around, they saw the lines connecting each particle to its nearest neighbor change color, with each line color representing a different type of bond (white for solid, blue for liquid, and red for gas). Three state meters on the side of the screen also showed students what percentage of the bonds within the current simulation were currently representing solid, liquid, and gas at any given time.

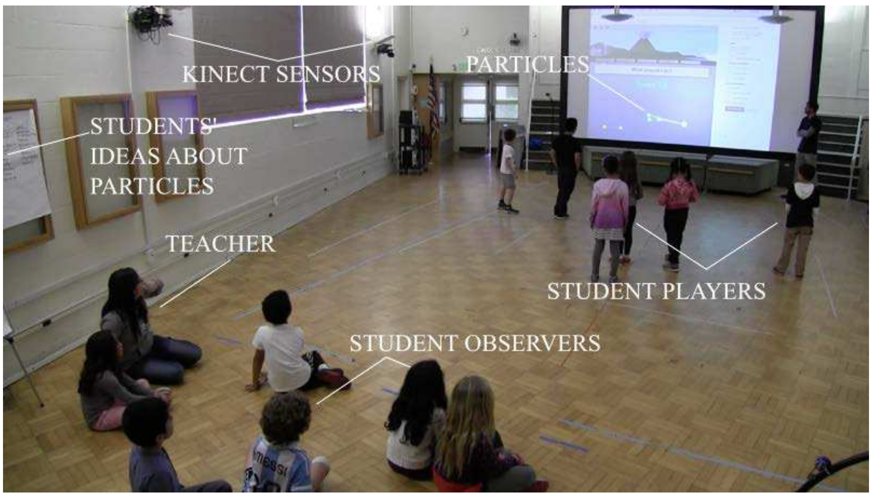

Figure 1: The technological and activity set-up of the STEP system.

STEP activities

Students collaboratively used their physical movements to explore particle behavior, using the feedback displayed on a projected screen to adapt their actions in line with the goals of each activity. Those students who were not participating in the simulation were cast as observers whose job was to reflect on connections between their classmates' actions and particle behavior occurring in the simulation.

We extended a previous application of the STEP technology (Danish, Enyedy, Saleh, Lee, & Andrade, 2015) to include two modes of play. In modeling-play, the onscreen simulation depicted particles moving in an empty container. No specific goals, explicit narratives, or rules were built into the software, though the teacher and students developed goals such as constructing a specific state of matter (see Figure 2, at left). In the game-play version of STEP, students were tasked with helping a robot escape a volcanic island to "win" the game. The core narrative was that particles were inside the robot's "engine" and students could control the robot's behavior by maintaining specific rules, as instantiated by states of water (e.g. creating gas at the particle level moves the robot, solid ice protects it, and water puts out fire). The simulation screen was split, with the top half showing the actions of the robot and the bottom half displaying the movement of the students' particles (see Figure 2, at right). Across the two modes, students engaged in similar activities. First, the students began by exploring the effects of hot and cold environments on the macro level properties of matter. Next, students transitioned to a micro level view of matter in which each student controlled one particle and the class reflected on the particle behavior. Finally, we switched focus to the impact of energy on particle behavior, with each student controlling an energy wand that heated up or cooled down any particle it touched.

Figure 2: Screen shots of what the students see on the screen in the play and game conditions.

Methods

Participants were from five mixed-age classrooms with 1st graders (n=58) and 2nd graders (n=66). There were a total of 122 participants (6-8 years old), 48 in the game-play condition (52% girls) and 72 in the modeling-play condition (54% girls). Four teachers participated and each had more than six years of teaching experience.

We first examined the extent to which the different groups learned after participating in the two game modes by conducting a mixed ANOVA. Content understanding was assessed in pre-post tests using content interviews. Content understanding was operationalized as descriptions of particle behavior in the different states of matter (matter-type codes) and the mechanisms behind state changes (change-type codes). These codes were derived from our earlier study (Danish et al., 2015) and Paik, Kim, Cho, and Park (2004). Students were asked about how particles behaved in different states as well as the mechanisms behind state changes. A total of three coders analyzed and categorized the pre-post video data. Interrater agreement between pairs of coders with Pearson's correlation ranged from .798 to .849, whereas the intraclass correlation for individual raters was .851.

Participation frameworks and keys

To describe how these mindsets or forms of inquiry differ between game-play and modeling-play, we build on the notion of *participation frameworks*—the tacit and explicit organization of participants' interactional rights and responsibilities (Goodwin, 1993)—within AR learning environments. Participation frameworks are known to vary across contexts (Erickson & Schultz, 1981), but in this case we examine how distinct participation frameworks are blended together in such a way that social dynamics shape which conceptual resources are brought to bear during learning. For example, in comparing play contexts, we would ask: Who has the right to generate a new goal or a new narrative in play and what are the participants responsible for accomplishing? Within our two designed play contexts, these questions result in different forms of inquiry and use of different conceptual resources. One way of understanding the impact of participation frameworks, particularly when the goal is to understand how they are built up from multiple, potentially contradictory contextual factors, is to focus on *keys:* "the set of conventions by which a given activity, one already meaningful in terms of some primary framework, is transformed by the participants to be something quite else" (Goffman, 1974 p. 43-44). In social interaction, people can perform more than one transformation to an activity by embedding keys within keys, in effect creating harmonies from the layering of multiple participation frameworks. In the following section, we elaborate on the construct of layered keys in the context of STEP.

Keys in the STEP activity

We focus on those instances where two or more keys are blended together to create a scenario greater than the sum of their parts in the same way that harmonies in music are perceived as more than independent notes. In STEP, students' learning experiences take place within a layering of keys. The primary framework on top of which the technology and curriculum unfold is science class. This primary event becomes keyed in three ways: as a simulation, as play, and as inquiry (see Figure 3). The technology in the classroom invites students to key particle movement into a human-scale, slowed-down enactment of the real thing, what learning scientists have labeled participatory simulations (Colella, 2000). The teachers and researchers explicitly invite students to key the participatory simulation toward a playful stance, taking what could otherwise be a serious orientation to the simulation and giving students leeway to have fun and pursue what piques their interest. The experience of being inside the particle simulation and taking a playful stance both become further keyed in an inquiry context, where students are asked to observe, experiment, and record patterns in particle movement.

In summary, science class becomes keyed to a human-scale enactment of particles, which becomes keyed in a playful tone, which becomes keyed in an inquiry mindset. This layering of keys makes it so that the status of students' first-person experiences inside the particle simulation cannot be separated from the playful key or from the inquiry key. In game-play, the middle-layer play key is substituted for a goal-directed narrative that contains criteria for success and failure (e.g. a scoring system). In our analysis, we explore how the students and teachers establish each layered key and blend them together. We point out variations in goal setting, idea generation, and experimentation throughout inquiry that result from these different configurations of keys.

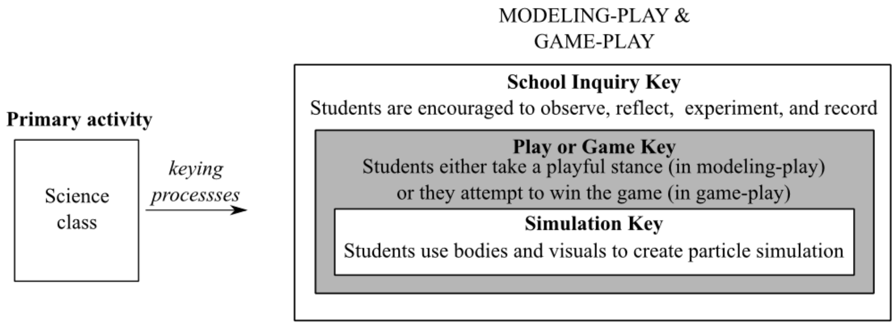

Figure 3: Layers of keys in the STEP activity.

We examine how the different game modes supported learning by combining narrative description with close interaction analysis (Jordan & Henderson, 1995). Consistent with the early stage of our research, we selected two episodes for our analysis, one from modeling-play and one from game-play, to provide a grounded description of students' inquiry in each condition and to advance our theoretical understanding of blended keys. These episodes consist of different inquiry patterns that allow us to explore the variation in the two play modes and provide exemplars of layered keys, which we can refine empirically and theoretically in subsequent work.

Results

A mixed ANOVA was conducted to assess how the two play modes influenced students' pre-post test scores. There was no significant interaction between play mode and time, Wilks Lambda = .996, $F(1, 118) = 0.305$, $p = .513$, partial eta squared = .004. There was a substantial main effect for time, Wilks Lambda = .305, $F(1, 118) = 269.286$, $p < .0001$, partial eta squared = .695, with both play modes showing an improvement of scores between the pre and post-interviews. As expected, the main effect comparing the two play modes was not significant, F (1,

118) = .0557, p = .457, partial eta squared = .005, suggesting no difference in how the modeling-play and game-play modes impacted students' scores. Given that the learning outcomes were equivalent in both groups, this fueled our interest to examine the different stances toward inquiry in each mode.

Inquiry processes in the modeling-play condition

Inquiry in the modeling-play condition takes place within the context of three layered keys: simulation, play, and inquiry (see Figure 3 above). The teacher, Ms. Jones, unfolds the first key (simulation) when she explains to the students, "Today, you guys are going to be particles." Moments later, Ms. Jones keys the simulation in a playful direction: "We are going to shrink you down with a special magic shrink machine," in reference to a hula-hoop decorated with spray-painted styrofoam balls (depicting particles). Ms. Jones then introduces the third key to students seated outside the simulation space: "The rest of you, your job is to notice what happens. If you have observations, say them out." These keys establish a space in which the class is not solely creating a particle *simulation*; they are creating a *playful* particle simulation and one engaged for the purpose of *scientific inquiry*.

Soon, all 12 of the students have moved through the hula-hoop portal and are playing as particles. Three students initiate a sidebar conversation with the teacher (not audible in our recording). Ms. Jones says, "Okay, I've heard a couple people say that." Ms. Jones looks up at all of the students, and in a loud voice, counts down: "5, 4, 3, 2, 1, freeze." The countdown marks a process of backgrounding the simulation and play keys, and foregrounding the inquiry key. The students then begin proposing ideas for testing whether location in the space determines particle color (state) and they decide to have boys stand on one side and girls on another. With the class split in half, the girls request that the boys stop running around because their movement is interfering with the test, the boys stop moving, the students observe the screen, the teacher asks if the idea is correct, and students' respond in chorus: "No!" The class has ruled out one hypothesis.

A student, Marie, proposes a new idea: Hugging can turn two people into one particle. The students form hugs in groups of two or three and shuffle around laughing. At this point, the students and teacher have blended three keys: The students are testing an idea from a peer's observation (inquiry key), and they are doing so with movement in the tech space (simulation key) and with a light-hearted stance (play key). Amidst the laughter, a new inquiry key, again in the form of a side bar, forms between the teacher and a student named Bethany. The teacher quiets the class down and Bethany explains: "Um, if we can make a caterpillar, and um, we can see if it's one particle or many particles." The students assemble into a caterpillar formation, standing in one straight line, holding on tightly to one another. They observe that the caterpillar formation does not amount to a single particle. And yet as they stand together in their caterpillar formation, one student at the back of the line, Carl, breaks free (4.1) and dances with a smile on his face to the opposite side of the room (see Figure 4).

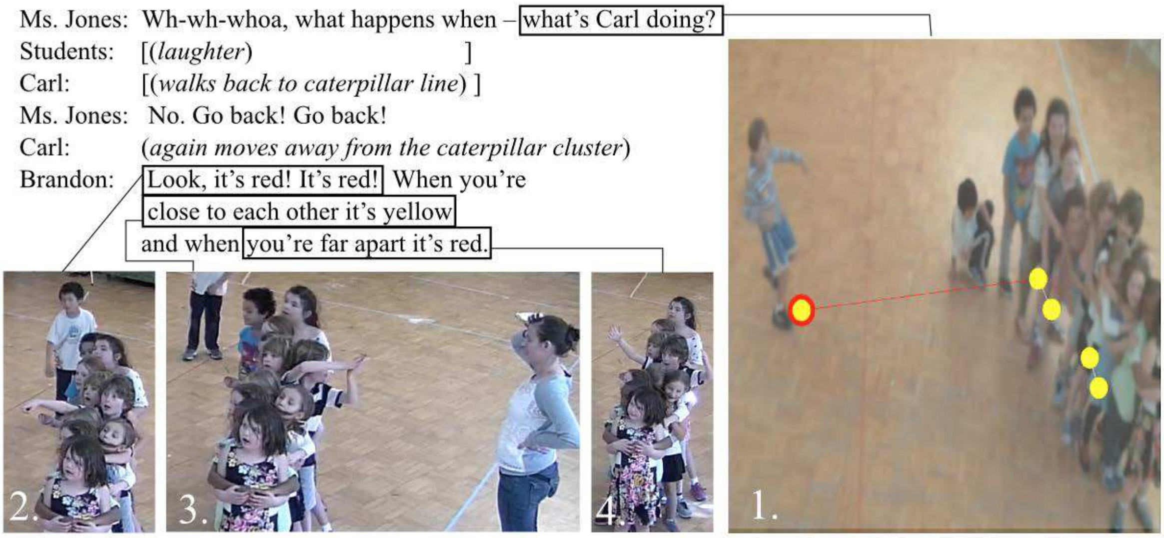

Figure 4: Carl breaks free from the "caterpillar" and Ms. Jones uses the deviation to key inquiry.

This moment marks an opportunistic harmony between three active keys. Carl, keying the activity with a playful stance, breaks free from the caterpillar formation and dances his way across the room. When Ms. Jones publicly calls out Carl's action, Carl seems to assume that he has violated a norm, and begins to walk back to the caterpillar. However, seizing the value of the play-based deviation, Ms. Jones re-shapes the moment into inquiry, telling Carl to return. Another student, wedged between his peers at the center of the caterpillar, also pursues the inquiry key, pointing to the screen and providing a crisp statement about how distance shapes color (4.2, 4.3, and 4.4). With respect to conceptual understanding, the keying of play, inquiry, and simulation amount to an incipient recognition of how distance between particles determines state of matter.

Discussion: Emergent goals and experimental ideas in modeling-play

We make two points about the inquiry process in the above episode of modeling play that we argue can be understood as a product of the layering of keys in the activity: Students generate emergent goals for their inquiry and they experimentally and opportunistically test new ideas. On the first point, the students select goals for inquiry that come from observations made in the play key. The students explore three ideas—side of the room determines color, hugging produces a single particle, and caterpillar produces a single particle. When a student proposes a new idea to the whole class, the students background the play key and foreground the inquiry and simulation keys. At any point, the students can attempt to re-invoke the play key (as we see with Carl in the caterpillar episode) and trigger another cycle of goal setting and idea generation.

However playfully students select goals for inquiry, they also formulate intelligible ideas and experimentally test them. The students think together about productive ways to test the idea and they execute the test with careful observations. Even when the students disprove their ideas, they make opportunistic progress uncovering salient dynamics in the simulation. For example, even though the side of the room is irrelevant to particle states of matter, the students testing this idea recognize that movement on the boys' side has added a confounding variable to their experiment. Similarly, even though clumping together into a caterpillar does not produce a single particle, one student's playful deviation from the caterpillar line leads to another student noticing that the deviation changed the particle color, and thus that distance might be in play. These two dimensions, speed and distance, are the two parameters that determine the state of matter in the STEP particle simulation. Despite that the students have not yet formulated the rules for speed and distance, they uncover both as relevant properties of state change.

Inquiry processes in the game-play condition

In the game-play condition, inquiry takes place within the context of three layers of keys: the particle simulation, the game narrative, and the inquiry mode. Ms. Lopez initiates the simulation key: "Are you ready to become particles?" Before she selects six students to enter the simulation space, Ms. Lopez keys the inquiry layer: "I'm going to ask those friends who are staying here, you have a very important job as scientists. You have to observe what it is your friends are doing, and together we have to decide do we need to change these rules to help them?" The teacher then invites six students into the simulation space after which both of the researchers trigger the game key, explaining that the game is hard and requires teamwork.

About half way into the game, the students have created gas and liquid to move the robot forward and put out fire. Half of the students are playing as particles (players), and half of the students and the teacher are watching from outside the simulation space (observers). The players start working to create liquid when the teacher notices that the players instead need to create an ice force field. She tells the players to look at the screen and the players catch on. In this exchange (see Figure 5), we see the players abruptly shift their goal to wanting to create an ice shield for the robot. The shift marks a foregrounding of the game key, where the players cater to what the protagonist in the game narrative needs to survive. Three different students then suggest three different strategies in rapid suggestion: "don't touch," "spread out," and "move a little to from a circle." The players never test the second two suggestions. After Researcher 1 pauses the game, both researchers comment on the players' actions relative to the game (not "forming anything" and "not working"), foregrounding the robot.

With the game paused, two observers and the teacher re-state strategies earlier suggested: "spread out" and "form a circle while moving slowly," the latter of which an observer and the teacher read from the paper that has the students' particle rules from the day before. The players ignore both suggestions. Instead, Horace says, "Wait, everybody get on an X" (referring to pieces of blue tape on the floor from an unrelated activity). Sandra offers: "Guys, get in the corner." A player asks Researcher 1 to unpause the game, which he does. Sandra again says the players should move to the corner and Horace tells a player to move to a specific X. Ms. Lopez adds on: "Where Sandra was standing, something happened." All the while, some players are standing motionless on Xs, other players are moving around, and the clock is counting down. The Researcher pauses the game again. Ms. Lopez again attempts to draw attention to the "something" that happened in Sandra's prior location, but a player asks for the game to be timed in again. This request marks the tension between the inquiry and game keys: The "something" Ms. Lopez notices becomes backgrounded when a player re-initiates the game key. Horace yells for everyone to spread to a corner, no ice forms, and the students lose the game.

Henry (observer): FORCE FIELD!
Horace (player): Force field. Get. Okay. Don't touch.
(*players stop holding hands and freeze*)
Claudia (observer): SPREAD OUT!
Ms. Lopez: Do you want to [pause it?]
Horace (player): [We have] to go
Jeffrey (observer): (*turning to read from the white board*)
Move a little from a circle while
[moving slowly]
Researcher 1: [I'll pause it so]
you guys can think a little bit.
Researcher 2: Were you forming anything [right there?]
Researcher 1: [This was not] working here, huh?

Figure 5: The students shift their goal to serve the needs of the robot and suggest a variety of strategies.

Discussion: Fixed goals and deploying strategies

In contrast to the emergent goals that formed in the modeling-play activity, the game-play activity represents an orientation to the fixed goals available in the robot key. Henry announces this goal at the start of the episode: "ICE SHIELD!" Even though students can in principle move any way they please in the simulation, the robot narrative becomes the deterministic anchor for their goals. The entire community shifts its attention to the goal of creating ice, and that goal persists up until the point that the clock runs out and the robot dies. This marks the foregrounding of the robot game key over the inquiry key.

In contrast to the experimental and opportunistic testing and observation of ideas in the modeling play activity, students in the game activity produce a nearly endless stream of action-based strategies with a focus on whether those strategies create an ice shield. In total, four different students produce five strategies: "don't touch," "spread out," "move a little from a circle," "stand on an X pattern," and "get in the corner." Three of those ideas are never tested in full. The inquiry key, described by the teacher at the head of the lesson as entailing observing the simulation and re-examining the particle rules, becomes adapted to accommodate the pace and structure of the game. When an opportunity arises to investigate the "something" interesting that Ms. Lopez notices, the game key is immediately re-activated and the players attempt yet another strategy. With respect to conceptual understanding, the students' throw-it-at-the-wall-and-see-what-sticks approach eventually (in subsequent attempts at the game) leads to a successful strategy for helping the robot.

Conclusion

Despite that our current assessment shows that students learned the science content equally well in the modeling-play and game-play activities, our qualitative analysis suggests that different features of the two activities—the open versus structured narrative and the lack of assessment versus the built-in assessment of success/failure—drove students to set goals and explore ideas in substantively different ways. These distinct inquiry patterns occur at the intersection between the structure of the play/game experience and the learning community's own prioritization and blending of different keys (simulation, game, play, inquiry). Given the small number of episodes analyzed qualitatively, and the idiosyncratic design of the game (e.g. the game is collaborative, has a timer, and usually involves students taking turns), we cannot make broad conclusions about the value of games versus play for science learning. However, our theoretical framework around blended keys points to a methodology for tracking how features of game design and modeling play may afford more or less productivity at different stages of inquiry. From our analysis, we can consider how teachers and designers can foreground, background, and blend simulation, play/game, and inquiry keys at different stages of ongoing activity to promote idea generation, experimentation, rehearsal, etc. We can also consider how different configurations of simulation, play, and games make it harder or easier to sustain inquiry and argumentation. How keys are established, backgrounded, and foregrounded in negotiation between students and teachers, and the value these different configurations provide for inquiry, are open questions. As learning scientists grapple with the nuanced spectrum between play and games, we see blended keys as a viable construct for teasing apart the influences on inquiry that may have implications for design and instructor education.

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