Science Sims and Games: Best Design Practices and Fave Flops

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Abstract: We represent a variety of educators and designers who have in common a deep concern about the quality of STEM learning and how new media tools are designed and used. These tools run the range of interactive simulations to embodied games with full arc narratives. We believe there is not one correct way to instruct in science using new media. For example - some formats (e.g., whiteboard vs. tablet) may be better for some learners (low vs. high prior knowledge) in some situations (single learner vs. small group) on some content (abstract vs. concrete). Our goal is to highlight some of the games and simulations we have designed and disseminated, and to explore their strengths and weaknesses. Each participant will present an original work, show a demo, present data on efficacy, and finally share anecdotes about what was done well and what could have been improved.

Embodied Science Education: Design Principles and Rolling It Out

Mina C. Johnson-Glenberg and Caroline Savio-Ramos

The Embodied Games for Learning (EGL) lab creates learning scenarios. These are interactive motion capture games that are designed to increase K-12 student learning. Along the way we have learned several extremely valuable lessons about design and real world dissemination. We begin with our game design precepts, move to results, and then end with several lessons learned – many of them the hard way.

The EGL lab is somewhat different from other learning game design labs is that we integrate gesture and novel motion capture technologies (for example, the Microsoft *Kinect* sensor and Leap Motion) where they are most efficacious for learning. The affordances of the myriad, rapidly-evolving technologies are exciting but changing so quickly that no one can remain an expert in the most innovative tech for long. The technology also has effect on our STEM topic choices. We would rather create a levers curriculum than focus solely on polynomial equations, because we can readily envision how the arm can act (and be tracked) as a lever. When we design we follow these precepts:

- Make it *embodied* – with as much gestural congruency as possible. This means that the gesture matches the content (e.g., spinning your arm in a circle to the right makes the virtual gear rotate in a clockwise revolution).
- *Socio-collaborative*- build in discourse opportunity and space for reflection, require observing students to do meaningful tasks
- Make it *generative* – constructive and active
- Wrap in *narrative* – make them care
- Give *immediate performance feedback*
- Level up in *cycle of expertise* - AI adaptive if possible (We like to use machine scoring algorithms as well.)
- Try to include *user-created content* - Students should be producers, not just consumers of technology. It takes time and more programming funds to build user-friendly editors that allow users to input content, but it greatly pays off in increases in motivation and "stickiness".

Our first embodied learning environment was a mixed reality platform (Milgram & Kishino, 1994) called *SMALLab* (Situated Multimedia Learning Lab) (D. Birchfield, Johnson-Glenberg, Savvides, Megowan-Romanowicz, & Uysal, 2010). This system used 12 infrared motion-tracking cameras either mounted in a ceiling or on a trussing system. The cameras record where in 3D space a student is holding a rigid-body trackable object (the wand). The floor space is 15 x 15 feet and so it feels VERY immersive to the student in the space (generally two at a time). By dipping the wand below a certain level on the Z axis, a virtual object projected on the floor could be "grabbed" by the wand and moved to another location (like a typical "drag and drop" interaction). Two notable differences between this platform and a traditional desktop one are that students can 1) locomote through the immersive environment and be tracked, and 2) the affordance of the open environment that an entire class can sit around the perimeter and partake in the lesson via observational learning. (See why locomotion is important and a Taxonomy of Embodiment in Education in (M. C. Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014).

Observing students who are on the perimeter of the *SMALLab* active space are encouraged to collaborate via discussion and whiteboard activities while the two active students in the *SMALLLab* space are interacting with the system. The effectiveness of this platform has been demonstrated in several content domains include language arts (Hatton, Birchfield, & Megowan-Romanowicz, 2008), STEM- physics (M.C. Johnson-Glenberg, Birchfield, Savvides, & Megowan-Romanowicz, 2011); (Tolentino et al., 2009); geology (David Birchfield et al., 2009), and Disease Transmission (M. C. Johnson-Glenberg et al., 2014) . We found that an entire classroom (up to 30 students) would remain engaged for an entire 50 minute lesson with this large scale platform. Part of that may be because the observing students were often given roles – to be recorders of what was happening or to write out predictions. In addition, there is an intense performative nature to the situation. Every student knows his/her turn will eventually arrive and the students do not want to fail in front of their peers. We try to make the tasks low stakes and game-like, but we believe this expectation of performance drives a fair share of the sustained attention. All of our teachers were delighted with this aspect of the system.

Switching Platforms

Figure 1. *Alien Health* game using *Kinect* and vertical projection

The *SMALLab* system was a powerful learning platform, but it was costly and not very mobile, so we started designing for the skeletal tracking sensor called Microsoft *Kinect*. We were able to keep the performative nature intact as students must still come to the front of the room and perform in front of an Interactive Whiteboard (IWB). However, now that the virtual surface is vertical and smaller (typically an IWB has a 7 foot diagonal) we see changes in the learning dynamics. With this transition we noticed that whole classroom engagement fell off after a period of time. We describe the Alien Health Game as an example. This is an embodied exergame designed to teach 4th through 12th grade students about nutrition and several USDA *My Plate* guidelines. A submitted study assessed efficacy and accessible (M. C. Johnson-Glenberg & Hekler, submitted) 2013 - in the *SMALLab* space. We observed full engagement for the one hour class for 4th graders. However, when the platform was altered to the *Kinect* (vertical and smaller) and we tested it on 20 6th and 7th graders, we noted that attention was not highly maintained after fifteen minutes (or after the first three dyads played).

The Kinect Pilot

Participants were randomly assigned to either the Alien Health game or a treated control condition that also performed in front of a whiteboard. Players learned about the amount of nutrients and optimizers in common food items and practiced making rapid food choices while engaging in short cardio exercises. All players engaged in "front of the class" performative activities at the IWB. The alien would get progressively more fatigued if fed the poorer food choice. See Figure 1. The match pair in this image includes a bran muffin versus a cupcake. The Alien Health group experienced the game narrative of feeding the alien and the *Kinect* sensor gave feedback on quality of cardio exercise. The control group experienced the same performative food choices at the IWB, but did not perform the cardio exercises. Significant learning gains were seen in both groups on the immediate posttest. The Effect Sizes from pretest to two week follow-up were .83 for control and 1.14 for the experimental group- significant but not differentially so. However, we did see a crossover interaction from immediate posttest to follow-up that approached significance, $F_{(19)}= 3.96$, $p < .058$, that favored the experimental group. Thus, students retained more knowledge after doing the exercises on a two week follow-up. Several of our studies have demonstrated gains are not always evident on immediate posttests but become evident at follow-up – and at that follow-up point the gains favor the embodied learning group.

In sum, participants who use more bodily gestures appear to show better retention of knowledge after a period of "consolidation". We encourage our colleagues to include follow-up tests when possible. We will also discuss why a memory trace may be stronger when content is learned via embodiment and the challenges of delivering professional development to the teacher community using new technologies. We look forward to a participatory section at the end of all presentations where we (Drs. Johnson-Glenberg and Lindgren) will collate ideas from members of the audience on best design and implementation practices for simulations and games for learning. The goal is to then share those principles with a broader community.

Blending Implicit Scaffolding and Games in PhET Interactive Simulations

Katherine K. Perkins and Emily B. Moore

Since 2002, the PhET Interactive Simulations project at University of Colorado Boulder has been engaged in research around effective simulation (sim) design strategies for supporting inquiry-based learning of science. Our design approaches and strategies aim to simultaneously support multiple educational goals. In addition to developing knowledge of and engaging students in science content, process, and practices (NGSS Lead States, 2013), we seek to attend to student motivation and ownership by creating environments where students experience control and choice over the learning experience, and perceive the experience as challenging but interesting and attainable (Pintrich, 2003).

Implicit scaffolding in interactive simulations has emerged as a powerful design approach for achieving these multiple goals (Moore, Herzog, & Perkins, 2013; Podolefsky, Moore, & Perkins, Submitted) – drawing on the education research literature (e.g., Bransford et al., 2000; Norman, 2002; Mayer, 2009) and our experience of designing over 100 interactive simulations (e.g., Podolefsky et al., 2010). Implicit scaffolding employs affordances, constraints, cueing, and feedback in order to frame and scaffold student exploration without explicit guidance. Successful designs leverage what students know (e.g. buckets hold things, scissors cut), cue focus on important factors through intuitive designs (e.g. cuing attention to chemical formulas through molecule collection boxes or to key parameters by using sliders), tap into natural curiosities (e.g. spark "what if?" or "why?" questions), and support building of knowledge (e.g. using tabs to scaffold complexity). When successful, students perceive the sims as engaging, open exploration spaces, while the implicit scaffolding provides cuing and guidance so students are inclined to interact with the sim in productive ways.

In this presentation, we will focus on PhET simulations which utilize both implicit scaffolding and either implicit or explicit games to create a learning environment. The games – while relatively simple – are designed to target development of core concepts and learning goals and to enable users to test and revise their understanding. Interviews and classroom testing look for evidence that the challenges in the game support student sense-making around and productive progress towards learning of core concepts – as opposed to learning to "game the system" without progress towards learning the content. If the latter is found, the game is revised or removed. Through the overall simulation design and use of multiple screens, students retain choice and control over their learning experience – freely moving between exploring simulation features and screens, and working on solving game challenges.

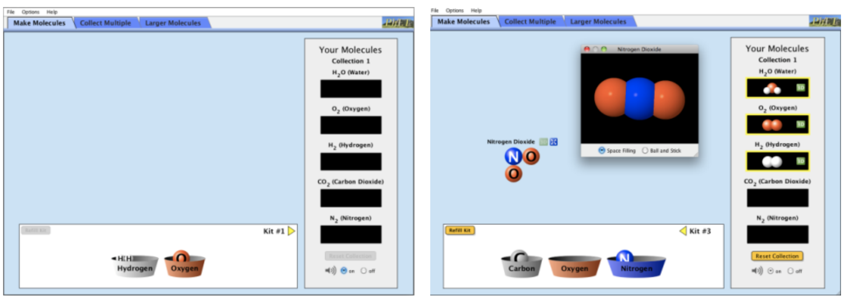

Figure 2. Screenshot of the *Build a Molecule* simulation showing implicit game (left) on startup and (right) during use – with Jmol window open showing a three-dimensional molecule representation.

We provide evidence of the effectiveness of these design approaches using data from student interviews and classroom use of the *Build a Molecule* simulation (Figure 2). The simulation goals are to support students in integrating pictorial and symbolic chemical representations, and in interpreting and producing chemical formulas with coefficients and subscripts. In the classroom study, the simulation was used in an activity by three 5th grade classes, with a total of 64 students. Students were given pre, post and delayed post assessments. Significant increases – pre-post gains ranging from 23% to 78% – were found in the amount of correct responses to all assessment questions involving writing chemical formulas from molecule pictures or drawing molecules from chemical formulas.

"How Do I Move This?": The Delicate Dance of Control Mechanisms in Embodied Science Learning Simulations

Robb Lindgren

The emergence of computer interface devices that accept gross physical movement as input has facilitated a new paradigm of educational technologies where a learner can use their bodies as a vehicle for understanding novel concepts and giving access to transformative ideas. Computer-mediated simulations equipped with motion tracking technologies allow learners to interact with scientific and other phenomena in ways that may be more intuitive and expressive (Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2013), and they have the potential to leverage body-based metaphors for developing complex understandings (Antle, Corness, & Droumeva, 2009; Lindgren & Moshell, 2011). Despite this potential, designing body-based interactions in digital environments that engender desired effects of insight and robust conceptual development is non-trivial. One issue is that that the physical actions that a user is prompted to perform (e.g., using arms and hands to push a virtual button or move a virtual slider) may not be sufficiently commensurate with the learning goals of a simulation (Lindgren & Johnson-Glenberg, 2013; see also Segal (2011) for "gestural congruency"). Another issue is that body-based interfaces to simulations may offer insufficient or ambiguous control mechanisms that make it challenging for learners to map the activity of their body onto simulation events and outcomes. There is sometimes a tendency, for example, to "pack too much" into the translation of a single body action, which disrupts a learner's ability to effectively utilize the interface metaphor. Here I discuss strategies and lessons learned for the design of control mechanisms for embodied science learning simulations.

Previous research suggests that students often struggle to acquire effective strategies for scientific experimentation such as adopting a control of variables strategy to isolate the effects of a specific parameter (e.g., Schauble, Glaser, Duschl, Schulze, & John, 1995). Typical science learning simulations do little to alleviate this struggle by frequently making multiple parameters available for simultaneous manipulation—picture the prototypical simulation as one with some phenomenon (e.g., shooting an object up in the air) depicted graphically and a series of slider bars and/or input boxes located off to the side. Simulations that take in gross motor movements have an analogous problem in that these actions operate in three dimensions and can consist of multiple temporal components, meaning that a single physical action such as waving one's hand in the air has the ability to correspond to multiple simulation parameters. And even if the physical action corresponds to only one parameter in the simulation, it can be challenging and ultimately unsatisfying for a learner to discover that only one aspect of their physical act—side-to-side movement in the horizontal plane, for example—has a consequential effect on the simulation.

I observed these interface challenges firsthand as my research team was designing an immersive mixed reality floor-projection-based simulation of planetary astronomy that aimed to build middle school students' intuitions about the physics of how objects move in space. The simulation was built around the metaphor of "learner as asteroid" where the user would utilize their body to set the asteroid into motion and then actively predict its subsequent trajectory based on the presence of gravitational forces (i.e., nearby planets). In the first iteration of the simulation learners launched the asteroid simply by walking off a virtual platform; the simulation registered the position and velocity of the learner at the point they crossed the "launch line." From a technical standpoint this was a seamless interface mechanism because it allowed the simulation to transition from the parameter specification phase to running the simulation without interruption. From a learning perspective, however, the fact that all three pertinent launch parameters (horizontal position, angle, and speed) were being set simultaneously with one step across the line led to numerous instances of confusion about how to control the asteroid's movement and what were the respective effects of the various parameters. As a result, there were no significant knowledge gains for the students using this version of the simulation compared to a control condition that used a desktop computer version of the same simulation. In a subsequent, second iteration of the simulation we changed the launching mechanism to a virtual spring in a tube instead of a platform (Figure 3 left). Using a scheme of arrows and highlighted "hot areas" learners were directed to use their bodies to set the three parameters sequentially. Learners caught on quickly to bodily conventions for setting the spring launcher and exhibited a greater awareness of how each parameter affected the asteroid trajectory. Most importantly, learning results from the study utilizing the second iteration control mechanisms showed a significant advantage for the learners using the bodily controls compared to the desktop version (Lindgren, Tscholl, Johnson, Glasshof, & Moshell, 2014).

Figure 3. A participant using their body position to set the launch parameters via a virtual spring (left) and a participant using their body to control the frequency of a wave (right).

The emphasis on control mechanisms in science learning simulations has been extended into the design efforts of subsequent body-based simulations in other areas of science that will be demonstrated in the session. For example, in an immersive simulation of waves, rather than having participants replicate the literal movement of waves across space, they are instead being prompted to enact individual components of wave behavior such as frequency; learners use their bodies to anticipate the number of cycles per a given unit of time (Figure 3 right). The possibilities for embodied interactions for generating powerful learning experiences in science is expansive, but successful body-based interfaces will require special attention to mechanisms of control, and taking great care to convey to a learner how their gross movements translate to simulation parameters and ultimately to core science concepts.

Evolving and Balancing Informal and Formal Representations

Douglas Clark, Corey Brady, Pratim Sengupta, Mario Martinez-Garza, Deanne Adams, Stephen Killingsworth, and Grant Van Eaton

School science, with its traditional focus on explicit formalized knowledge structures and learning but not *applying* factual knowledge, frequently does not address tacit understandings, and thus does not support students in revising their intuitive misconceptions. Interestingly, well-designed digital games are exceptionally successful at helping learners build accurate intuitive understandings of the concepts at the heart of the games due to the situated and enacted nature of good games (e.g., Gee, 2007). Most commercial games fall short as platforms for learning because they do not help people articulate and connect their evolving intuitive understandings to more explicit formalized structures that would support transfer of knowledge to new contexts (e.g., Masson, Bub, & Lalonde, 2010). Our thinking about bridging these two approaches parallels Vygotsky's (1978) thinking about using everyday ideas to bootstrap formal ideas.

Figure 4. Surge Classic.

The granularity of the focal representations in a game, however, involves a careful balancing act to support this bootstrapping. Figures 4 and 5 show the progression of representations across our grants. Our original NSF SURGE grant included explorations of a relatively "realistic" 3D representation. Players enjoyed the visual perspective, but the 3D representation and disconnect from formal representations made bridging intuitive and formal knowledge difficult (Clark et al., 2011).

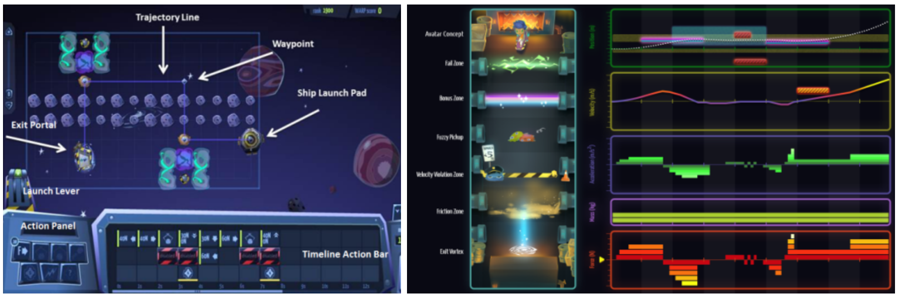

Figure 5. Surge 2 Fuzzy Chronicles (left) and SURGE 3 Away Missions (right).

Our subsequent DOE EPIGAME grant focuses on a 2D representation that integrates formal representations including dot traces, time lines, force magnitudes, and vector representations. Krinks, Sengupta, and Clark (submitted) found that this type of structure supports students in developing intuitive understanding as they shift in terms of the p-prims (diSessa, 1988, 1993) they leverage in their explanations, but Van Eaton, Clark, and Beutel (2013) have found that teachers and students connect their intuitive understanding to formal understanding in ways that support their initial misconceptions about the formal understanding. To address these challenges, our current research on this project focuses on leveraging self-explanation (Clark & Martinez-Garza, 2012; Adams & Clark, submitted) and integrated graphing activities (Sengupta et al., 2013).

Our NSF EGAME grant currently includes an exploratory focus on a highly schematized 1D representation of motion directly and tightly integrated and controlled through formal disciplinary graphical representations. This approach builds on a long history of having students match motion with graphs, control motion with graphs, or create graphs through motion with motion sensors. The most detailed work to date in this area was conducted as part of the SimCalc projects, beginning with MathCars (Kaput, 1994) and later MathWorlds (Roschelle & Kaput, 1996; Hegedus & Roschelle, 2013). SURGE1D extends SimCalc's use of Cartesian graphs as control structures that have "representational expressivity," (Hegedus & Moreno-Armella, 2009) in two critical ways. First, it uses the Cartesian space as a means for communicating critical game information to the player. For instance, the SURGE1D position graph holds forecasts about regions in the game-world that will be affected by electrical storms, as well as about locations where rewards or allies will appear to rendezvous with Surge. The velocity and acceleration graphs likewise indicate constraints on game-play, such as maximum or minimum speeds and maximum accelerations, each of which can be tied to narrative elements in game scenarios. SURGE1D also extends the expressivity of Cartesian representations by introducing the notion of a moving frame of reference. Both the challenges and the benefits to learners of representing relative motion have been recognized by researchers (Radford, 2009), and the importance of the selection of a reference frame is fundamental to the learning and practice of physics. In SURGE1D, the "camera" can be placed at any fixed location in the game-world, and it can also be mounted on a non-player character that moves at a constant velocity. The resulting transformations of graphical space offer opportunities for exploring narratives that involve making sense of other perspectives on the game-world.

Essentially, while our initial approach focused more on layering formal representations over informal representations, we are now exploring approaches that layer informal representations over formal representations while organizing gameplay explicitly and formally around navigating and coordinating across representations. Whereas SimCalc focuses on manipulating formal representations to achieve goals in the informal representation, we are attempting to extend SimCalc approaches by (a) integrating the goals directly into the formal representations in a way that projects onto the informal representations and (b) supporting the integration through advanced self-explanation functionality and representation decomposition.

Methods for Supporting Professional Practice and Video Game Based Research

Matthew Gaydos, Amanda Barany, and Kurt Squire

Effectiveness and Support

One of the most difficult challenges that educational technologies have faced has not been in the development of successful learning interventions, but in moving such interventions from the laboratory to the classroom, especially at scale (Cohen & Ball, 2001; Gomez, Gomez, & Gifford, 2010). Supporting the development and use of educational technologies means establishing teacher buy-in and ownership over the curriculum (Cohen & Ball, 2001; Gomez et al., 2010; Kwon, Wardrip, & Gomez, 2008). Educational video games similarly, require that researcher and developer designs be coordinated with teacher and administrator support. That is, in order for games to be effectively and sustainably used in formal education settings, they must not only be content-laden and effective, but supported by local agents – those who will utilize them.

In this presentation, we summarize findings from two case studies conducted as a part of an on-going design-based research project centered on the educational video game *Citizen Science.* In each case, *Citizen Science* was used in authentic classroom settings. Its use was observed, documented and analyzed in order to examine teacher-designed curricula that 1) suggest modifications for future game designs and 2) suggest obstacles that may need to be addressed in similar game-based contexts.

The game *Citizen Science*

Citizen Science is an action/adventure role-playing game designed to teach students civic-science literacy as related to lake ecology. In game, players engage in dialogues with non-player characters (NPCs) that represent stakeholder groups, collecting evidence in order to argue with NPCs and advance the game's narrative. The game is setting-specific, as players travel back and forth through time in Madison, WI, in order to convince local non-player characters to change their minds about how they use the local lakes. The goal of the game is to change the conditions of a local natural resource, Lake Mendota, especially so that the lake does not become hyper-eutrophic. If the lake were to become hyper-eutrophic, negative effects on the community could include fish die-offs because of decreased oxygen levels, unpleasant smells especially around the shoreline, increased toxic blue-green algae blooms, and an unattractive, murky aesthetic. Using elements typically found in commercial adventure video games including character, fantasy, humor, and strong role induction, *Citizen Science* is designed to provide students with an engaging and positive game-based experience, information about lake science content related to taking civic action within the local community, and the willingness to take action to improve the health of local lakes.

With regards to its intended use, *Citizen Science* was designed to be integrated into already-existing educational contexts, supported through teacher-developed curriculum. Within a classroom context and with the help of a teacher, the game's content could be reviewed, explained, and connected to its accompanying curriculum. This curriculum, in turn, can vary widely depending on the teacher's particular needs or educational goals. In the two cases that follow, we briefly describe the context and the *petite generalizations* (Stake, 1995) that characterize the game's relationship with established curricula.

Two Cases of *Citizen Science* Use in Classrooms

In the first case, seven middle school students played *Citizen Science* as a part of a three-day science curriculum at a private school for the gifted and talented. Student learning was measured using an ad hoc multiple-choice questionnaire that covered game-related content and was administered at the beginning and end of the intervention. Students' scores on these tests showed improvement, increasing on average by 26% (SD = 16%) from pre- to post-test. The teacher and students' video and audio-recordings were reviewed and selectively transcribed for activities and dialogues in which the students and teachers were interacting with or explicitly referring to the game. During the intervention, students played the game during the first two days of class. On the third day, students and their teachers visited a local lake, where they made general observations of the lake's ecosystem, took water samples that were later examined under microscopes, and discussed local lake issues and ecology concepts with each other and with their teachers. Throughout the field trip, the teachers explained ecology concepts in terms of students' prior experiences, including previous classes they had taken, course material they had covered, and *Citizen Science* game play. For example, the teacher explicitly asked students to connect the scientific measurement practices that they conducted during the field trip to the parallel practices simulated within the game.

In the second case, 75 seventh grade students in a public middle school Life Science classroom played Citizen Science over the course of two days as the lake ecology portion of a five-week ecology unit. Student learning was measured by completion of an online worksheet in which students practiced organizing and creating evidence-based arguments using content from the game (results being analyzed now). Students also demonstrated their use of evidence-based argumentation in final projects. During the two-day curriculum, the teacher used note cards as a tool to mediate the intersecting needs of the school administration and the game-based curriculum. At the end of each class, the teacher asked students to briefly hand-write "one thing that they learned and one question they had" as a result of game play. In so doing, the teacher designed a simple tool that functioned as a formative assessment that could be referenced in class. E.g., the teacher referenced the note cards at the start of the second day of the curriculum, using student responses to prompt a discussion about blue-green algae. Because some students had incorrectly written that all algae could be fatal, the teacher wanted to clarify that only particular types produced toxins. These note cards thus served a dual function that we will explore in the talk.

Discussion

Together, these cases highlight the importance of providing support for educational games in terms of their integration into curriculum with respect to content, and their integration into practice with respect to local constraints. In the first case, the teachers' practices suggest a need for support that helps draw connections between material referenced within the game to activities within the classroom. The note cards used in the second case highlight the need to develop assessments that can be used to meet content-based and institutional constraints. Similar to Hoadley's use of design narratives (2004) to promote understanding and ultimately reliability within messy, authentic contexts, video game based learning would benefit from techniques that encourage sharing game-specific educational practices. Our hope is that by presenting these cases of *Citizen Science* use within classrooms, we might prompt a discussion of how such sharing can be better promoted, particularly with regards to game design and educator practice.

Exploring the Particulate Nature of Matter in a Constructionist Video Game

Nathan Holbert

Many video games include rich science phenomena and principles that players frequently encounter during play making them potentially powerful spaces for STEM learning. Designers interested in the educational potential of video games often attempt to create new games that both enhance the science phenomena commonly embedded in games as well as provide carefully orchestrate interactions that ensure players encounter the targeted phenomena. While many educational games have been shown to produce in players learning gains on measures that directly align with in-game action and mechanics, these same games often fail to show player improvement on *distal* problems (Clark & Martinez-Garza, 2012). This result suggests that while players may be gaining expertise with the game, they are not achieving a deep understanding of the concepts that underlie game mechanics.

Rather than design scripted experiences that ensure players confront targeted phenomena, I have explored game designs that privilege freedom and exploration. Borrowing heavily from the constructionist design paradigm which has been shown to be a powerful means of facilitating deep exploration of STEM concepts (Papert & Harel, 1991; Papert, 1980), these games engage players in the building of personally meaningful artifacts to overcome obstacles and challenges met in the course of more traditional genre gameplay. *Particles!* (Holbert & Wilensky, 2012), is a platformer game that encourages players to explore how the physical properties of matter emerge from the arrangement of molecular-level particles.

Particles! Description

Particles! was designed to have the look and feel of a platformer video game while including principles central to the constructionist design paradigm (Papert & Harel, 1991). As in most platformer games, players are tasked with moving through a level full of obstacles to reach a locational goal. However, in *Particles!* players modify the game level as they play through it by removing existing world blocks and adding new designed blocks. Players design these new blocks at the molecular level—by adding and removing bonds between atoms to create large and complex molecular structures (Figure 6 left). These player-designed structures then serve as a template for the many molecules that populate the larger block that will be added to the game world. When these new blocks are added, they have physical properties emergent from the player-designed structures (such as bounciness or slipperiness), which in turn provides new options for how the player might complete each game level (Figure 6 right). These acts of construction encourage players to engage deeply with the mechanics of the game as well as the scientific principles (bonding and molecular structures) that are infused in these mechanics gaining a sense of the role molecular structure plays in object properties.

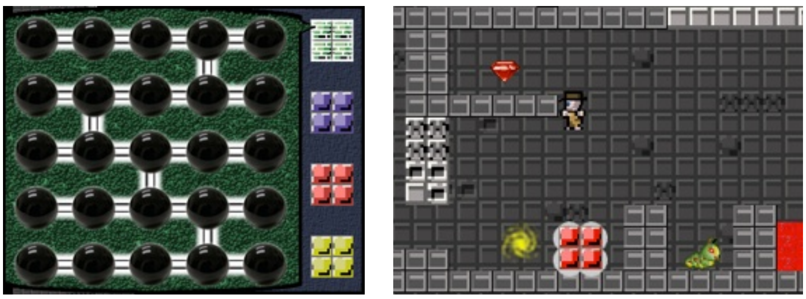

Figure 6. Players add and remove bonds between atoms to create molecular structures in the "atomizer" (left). These player-designed structures result in new emergent properties for blocks added into the game world (right).

In addition to including meaningful opportunities for construction, the atoms and bonds central to block building in *Particles!* visually and epistemologically align with the ball-and-stick model—an important representation used in the formal practice of chemistry. This visual similarity, and the alignment between the meaning and use of the representation in-game and in the formal domain, encourages players to see in-game block construction as a useful knowledge resource when thinking and reasoning outside of the game.

Method and Data

Nine players, ages 11-14, were recruited from various non-school gaming clubs. Semi-structured clinical interviews were conducted with the participants 1-week before and after playing the prototype game. Interviews and game play occurred in informal settings and focused around the description of and explanations for the physical properties of Lego and Styrofoam blocks present during the interview. Interviews were videotaped, transcribed and analyzed for player invoked "concepts" using a coding scheme developed bottom-up from multiple passes of the data. In addition, participant drawings of the atoms that make up each interview block were analyzed for feature changes before and after playing the game.

Results and Discussion

In this presentation I will show how participant explanations of the causes of material properties shifted after playing *Particles!* from focusing on the identity of the substance to more complex explanations of how the arrangement and structure of the particles that make up a substance might result in observed properties. In the pre-game all nine participants suggested the "identity" of the material (71 times) primarily determines an object's properties while only five participants claimed properties are due to the arrangement and structure of the particles (24 times). In the post-game all nine participants were more likely to cite the structure and arrangement of block particles (57 times) as well as related constructs such as bonding as primarily responsible for observed properties. Eight participants also mentioned material identity (43 times). Furthermore, participant drawings of the particles that make up each interview block were significantly more likely to include images that showed many particles arranged in a specific pattern with many using the particular grid arrangement utilized in the game.

These findings indicate participants shifted from attributing object properties solely to the *identity* of atoms and elements that make up the object to both *identity and structure*. Furthermore, this shift seems to have been facilitated by participants' experiences with game mechanics as in-game representations became central in participant explanations and drawings. The results suggest *Particles!* unique design may have provided players with a rich set of knowledge resources that they can freely access when thinking and reasoning in a variety of contexts. Furthermore, the success of *Particles!* offers important insight into possible design mechanics that can elicit deep learning in informal game play.

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